

Laboratory for Timber Constructions

Constructions innovantes et durables

Yves Weinand, Associate Professor

IBOIS | EPFL | Lausanne

2007 Pont pédestre sur l'Our,

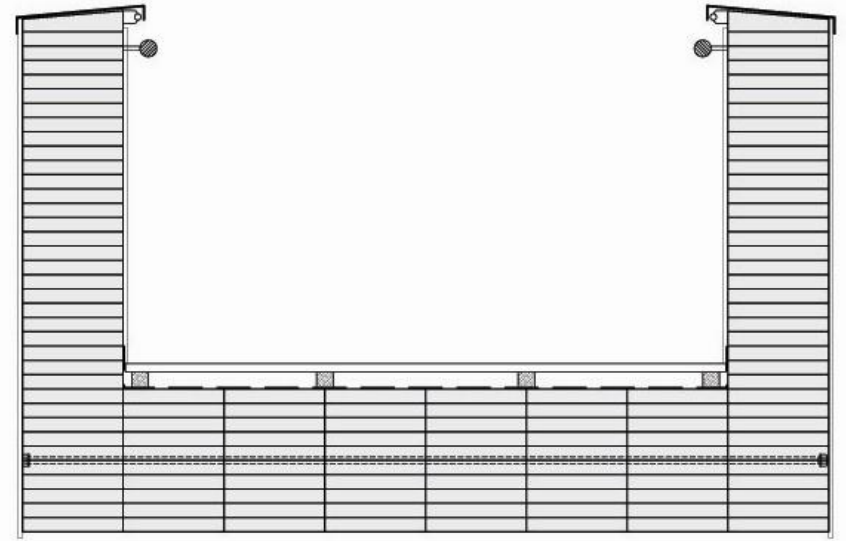
Burg Reuland

Maître d'ouvrage : Commune de Burg-Reuland

Architecte: association momentanée

Michaelis-Weinand, Espeler

Ingénieur: bureau d'études Weinand



Professional Practice

2006 Patinoire, Liège

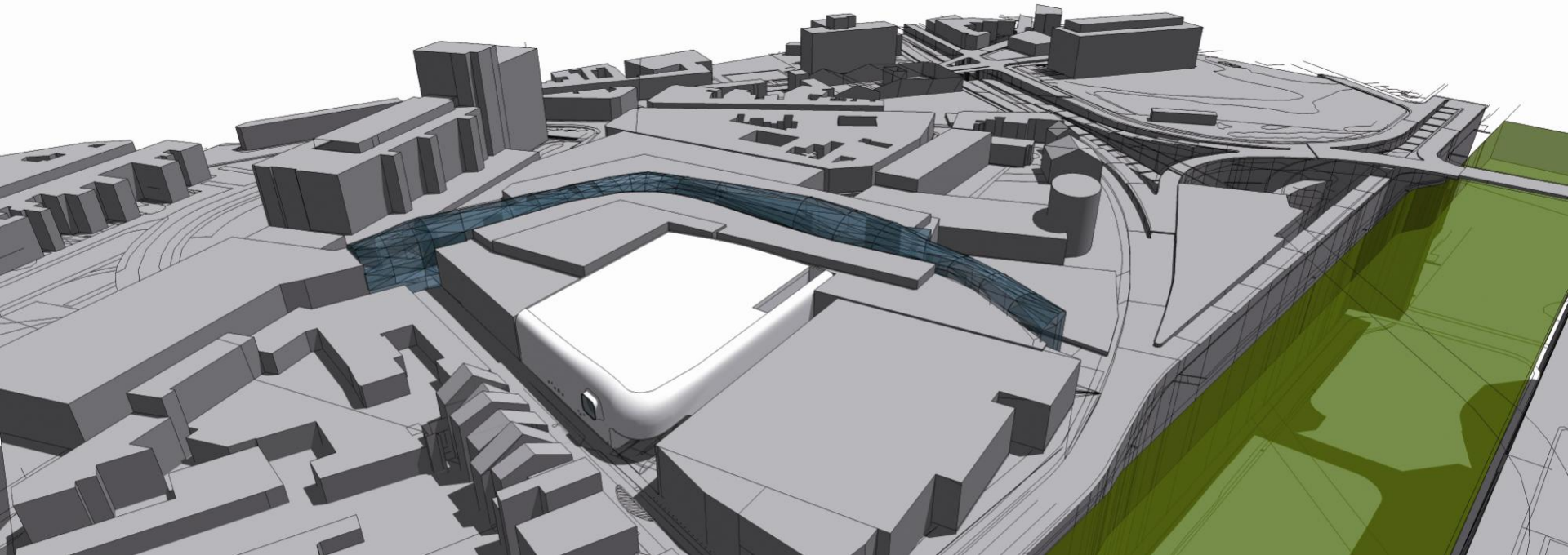
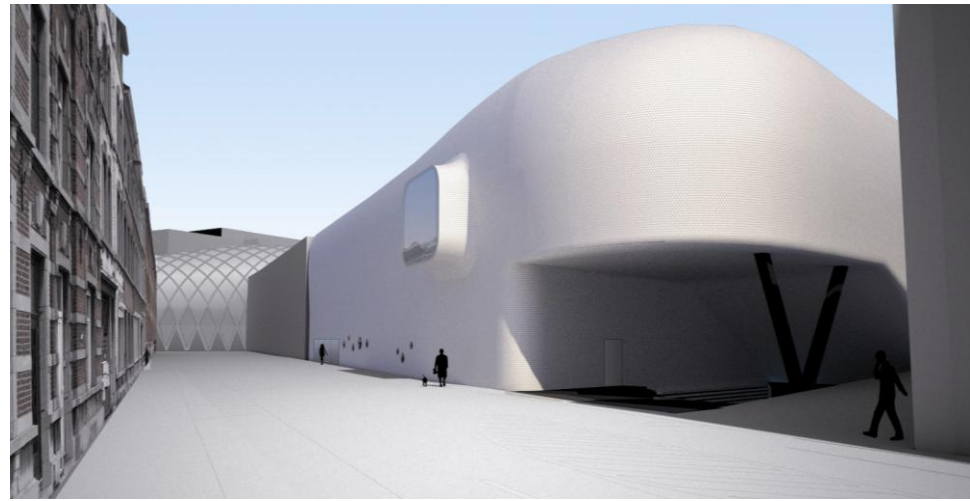
Maître d'ouvrage : Ville de Liège

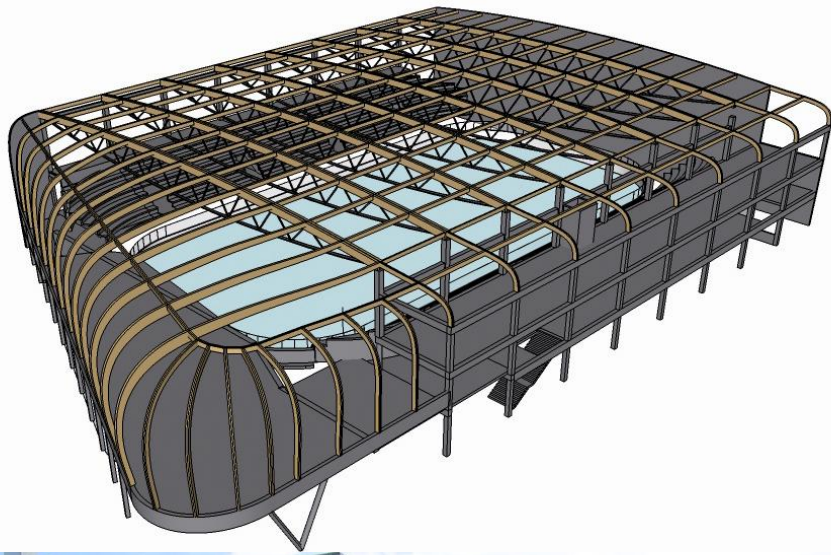
Architecte: association momentanée Escaut-Weinand

Ingénieur: bureau d'études Weinand

Surface utile : 4700 m²,

Coût estimé : € 7'200'000,-





Professional Practice



Professional Practice

2006, Salle de sport, Yverdon

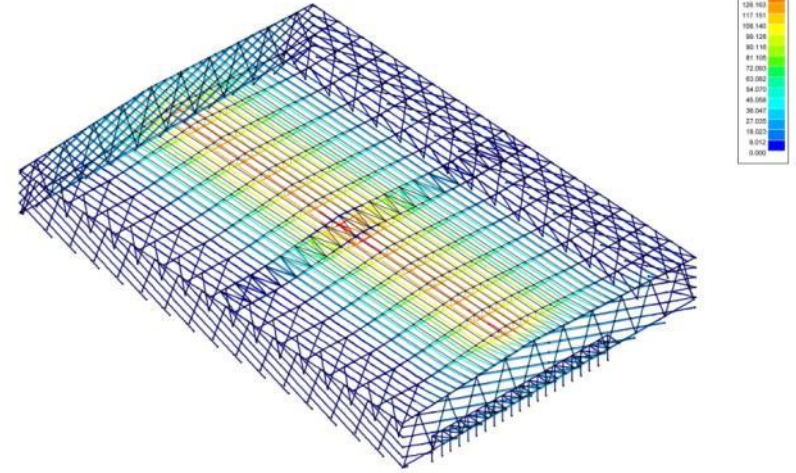
Maître d'ouvrage : Commune d'Yverdon

Architecte: Ueli Brauen & Doris Wälchli avec Yves Weinand

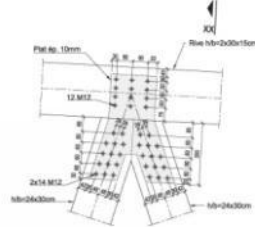
Ingénieur: Bureau d'Etudes Weinand

Surface utile : 2866 m²

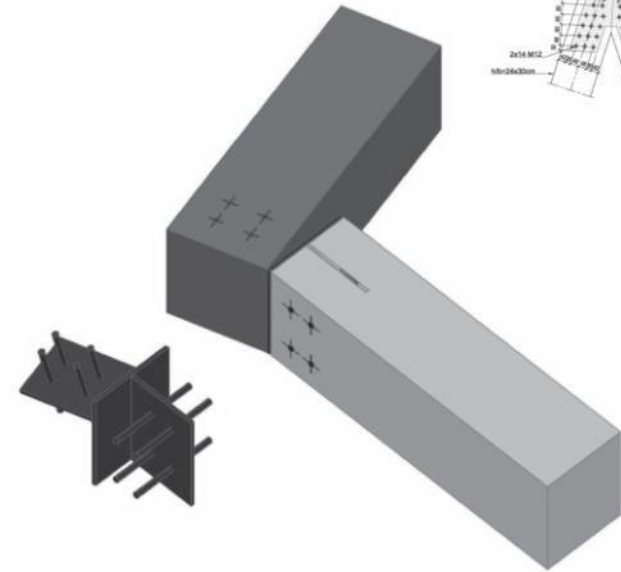
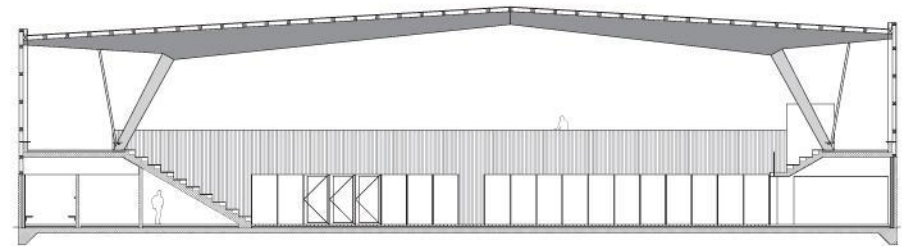
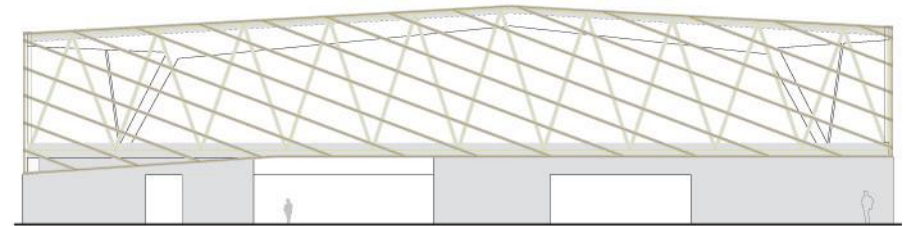
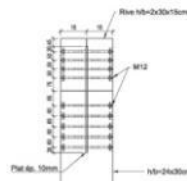
Coût estimé : CHF 14'000'000,-



Détail 4.2 (SDA: 1/10)



Coupe (SDA: 1/10)





Professional Practice

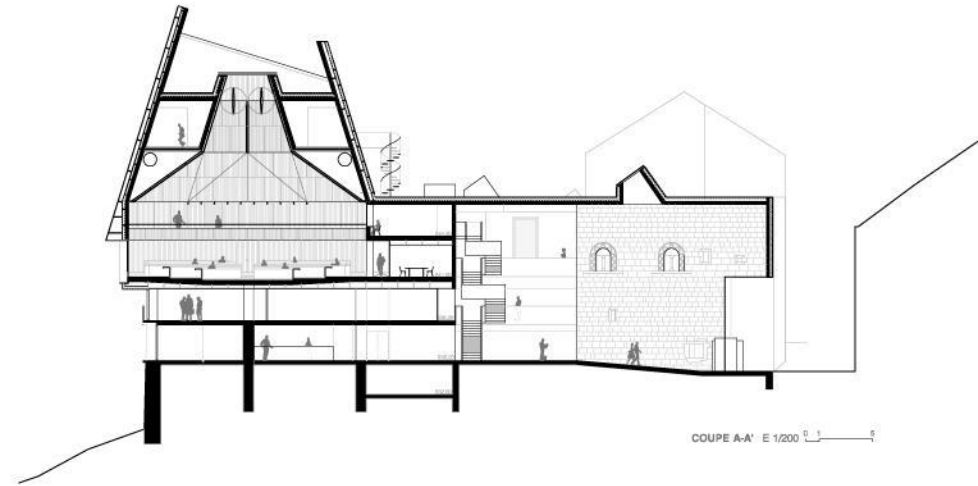
2009, Parlement

Maître d'ouvrage : Canton de Vaud

Architecte: Atelier Cube / Bonell & Gil

Ingénieur: Bureau d'Etudes Weinand

Coût estimé : CHF 21'000'000,-



Professional Practice

REVÊTEMENT EXTÉRIEUR DE FEUILLES DE CUIVRE (OU UGINOX)

LAME D'AIR FORMÉE PAR TÔLE PROFILÉE

ISOLATION

PANNEAUX EN BOIS MASSIF CONTRECOLLÉ

ASPIRATION HAUTE AIR CHAUD

LAMES DE CONTRÔLE DE L'ÉCLAIRAGE NATUREL

ESPACE MACHINES VENTILATION ET CHAUFFAGE

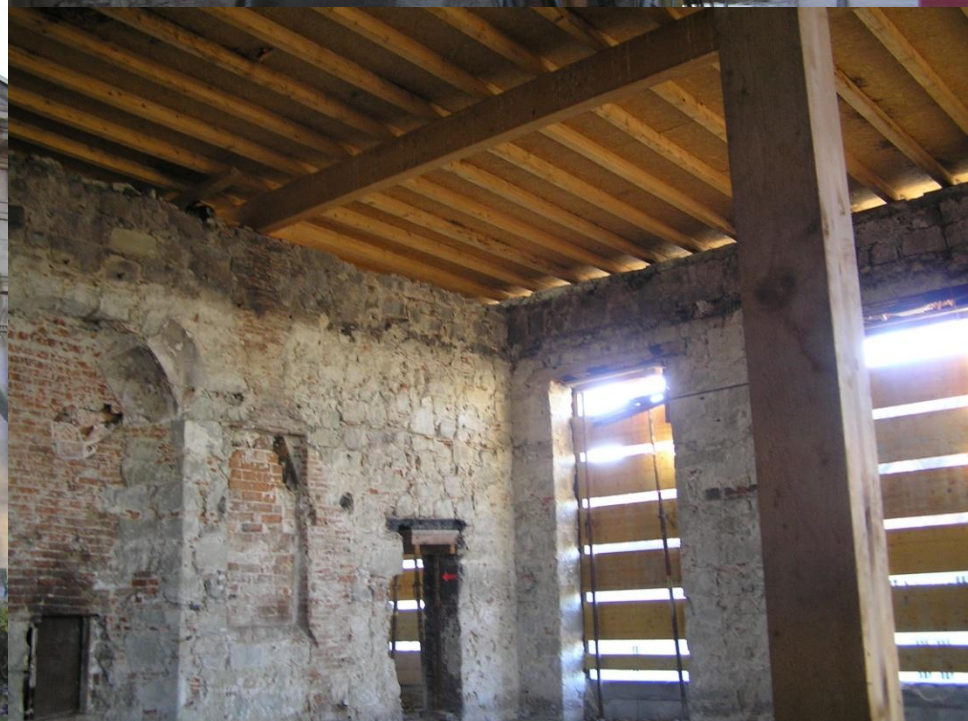
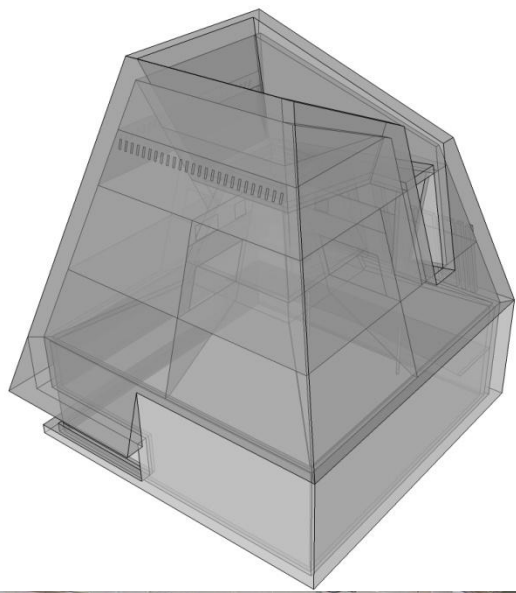
GALERIE TECHNIQUE REPRISE D'AIR

ASPIRATION BASSE AIR CHAUD

PANNEAUX EN BOIS MASSIF CONTRECOLLÉ
UTILISÉS COMME SURFACES FINES

SALLE DU PARLEMENT E 1/100 0 0.5 1 2

L'EXERCICE DE LA DÉMOCRATIE EST DANS LES PERSONNES, LE CADRE PHYSIQUE DOIT LE DIGNIFIER.

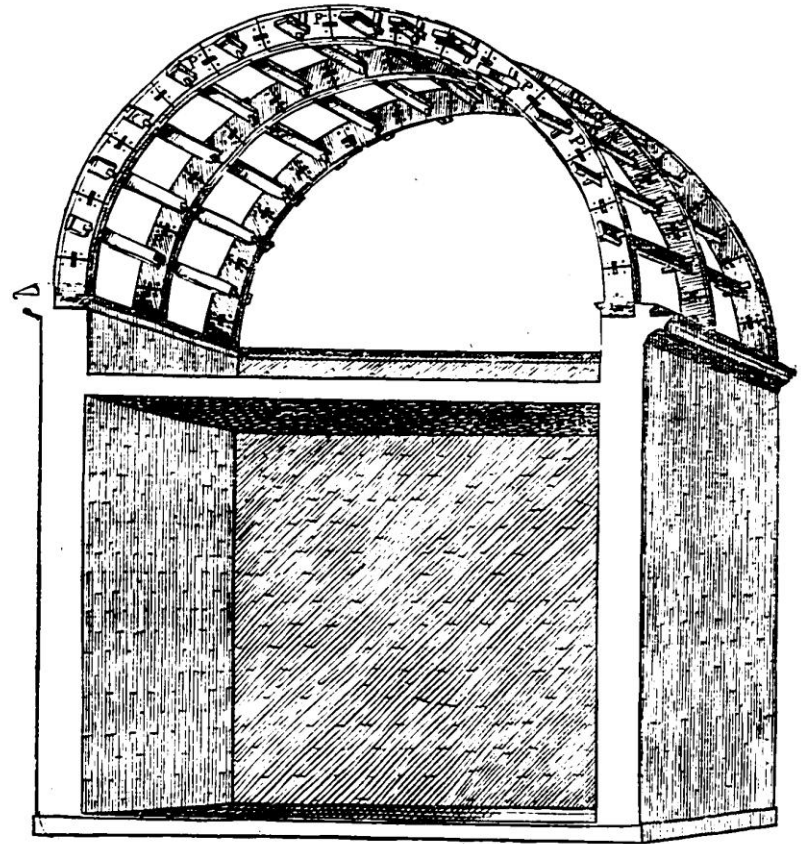
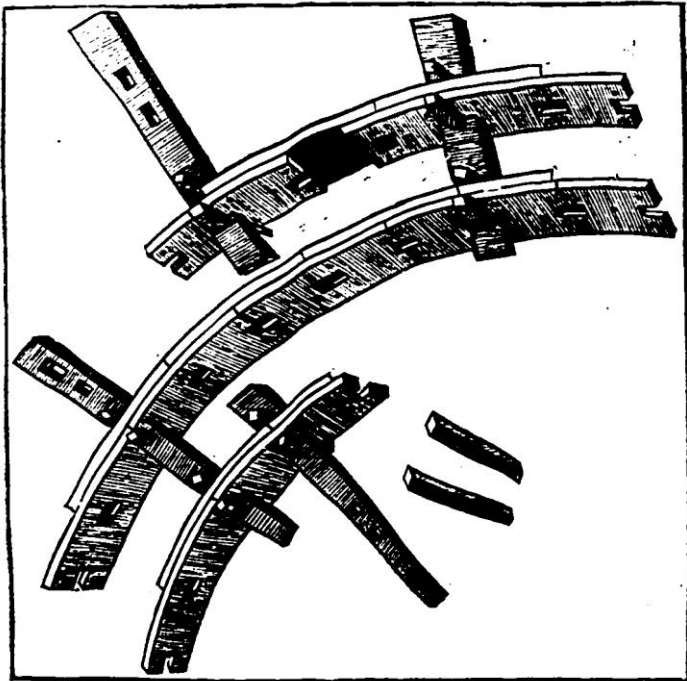


Professional Practice



Philibert de l'Orme

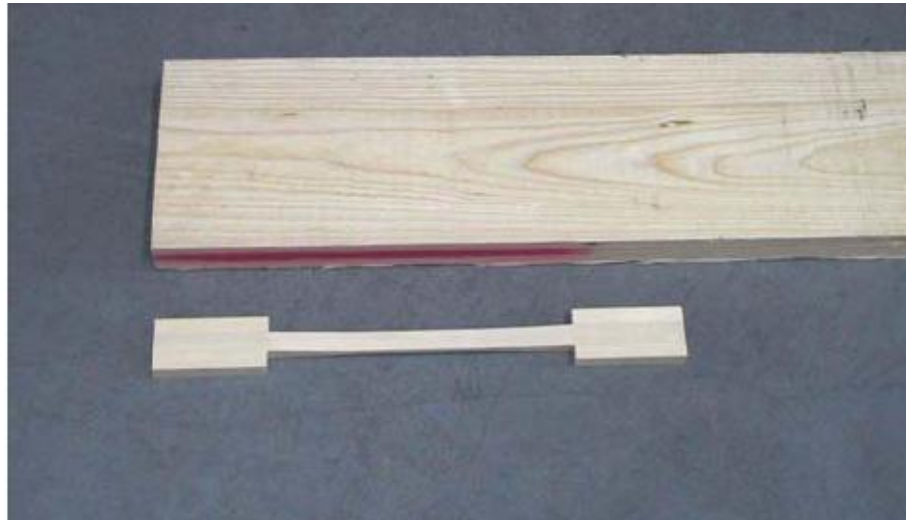
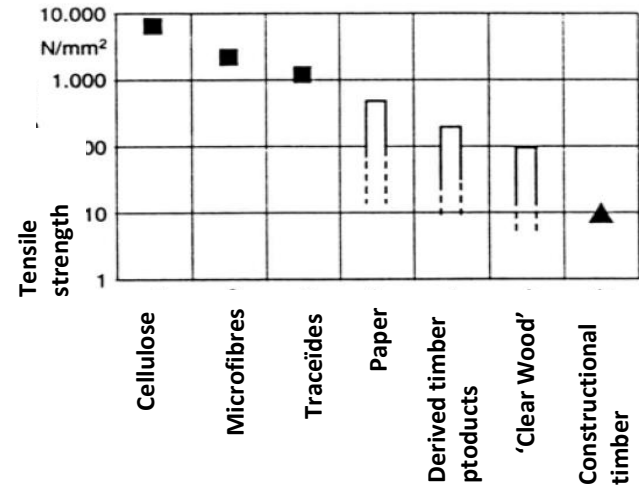
Construction detail



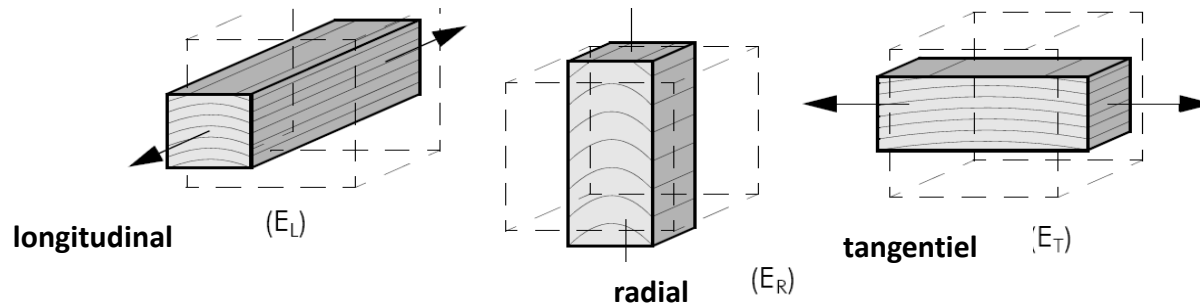
Characteristic values of spruce
[P. Niemz, 1993 and P. Glos, 1981]

Characteristic properties	Small Specimen	Constructional Element	Difference to the small specimen
Bending Strength (mean value [N/mm ²])	68	37	46%
Tensile Strength parallel to fibers (mean value [N/mm ²])	80	30	63%
Compression Strength parallel to fibers (mean value [N/mm ²])	40	32	20%

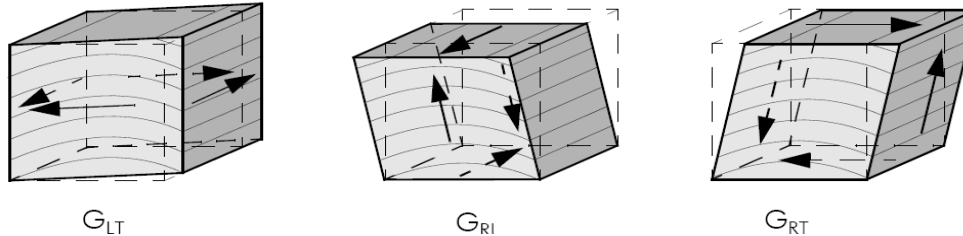
Mechanical Properties [Glos 1999]



Elasticity modulus E – normal deflection:



Shear modulus G – shear deflection:



Elasticity Modulus E (in **T**angential, **L**ongitudinal and **R**adial direction)

$$E_T \div E_R \div E_L = 1 \div 1,7 \div 20 \quad (\text{Soft Wood})$$

$$E_T \div E_R \div E_L = 1 \div 1,7 \div 13 \quad (\text{Hard Wood})$$

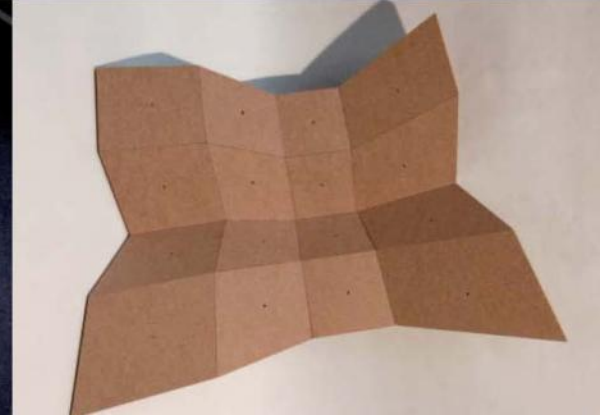
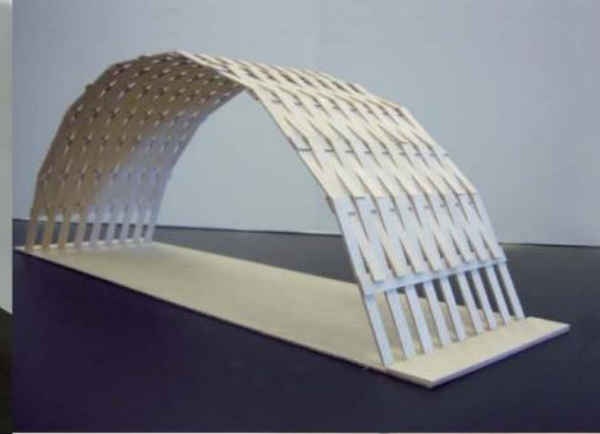
Shear Modulus G (in **T**angential, **L**ongitudinal and **R**adial

direction) $G_{LR} \div G_{LT} = 1 \div 1 \quad (\text{Soft Wood})$

$$G_{LR} \div G_{LT} = 1,3 \div 1 \quad (\text{Hard Wood})$$

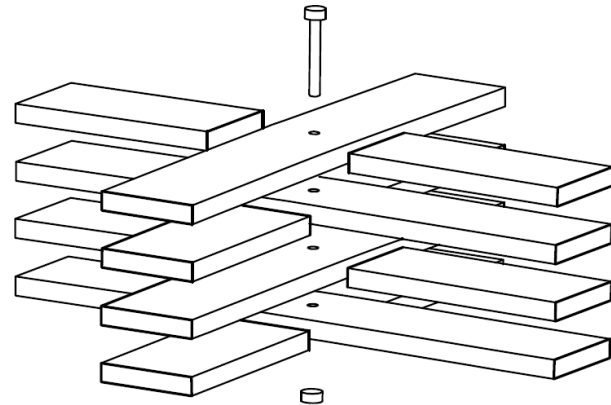
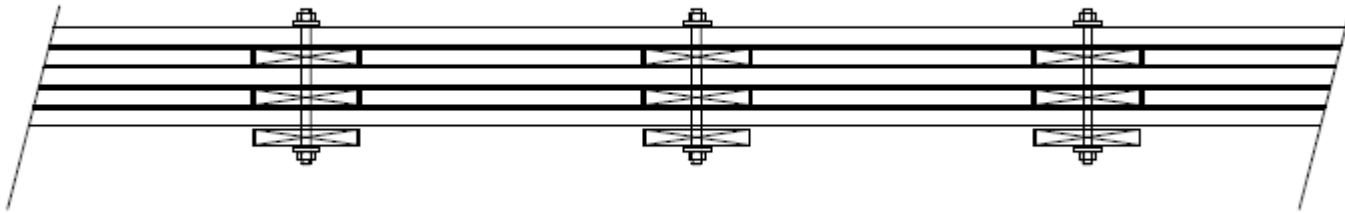
Research at Ibois

Free form shell structures



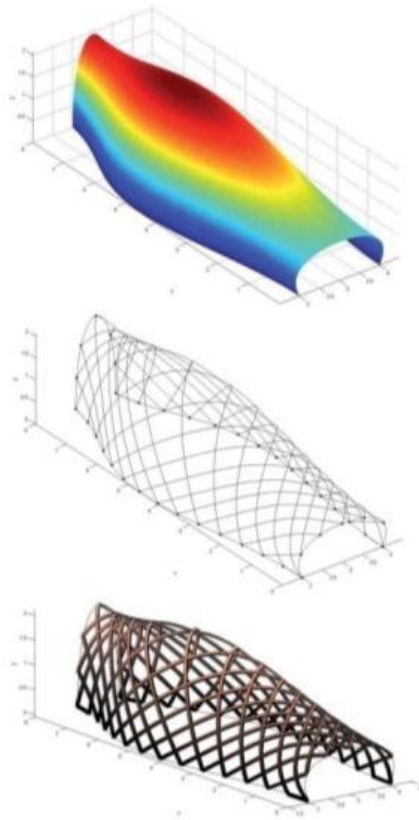
Structural behavior of rib shells

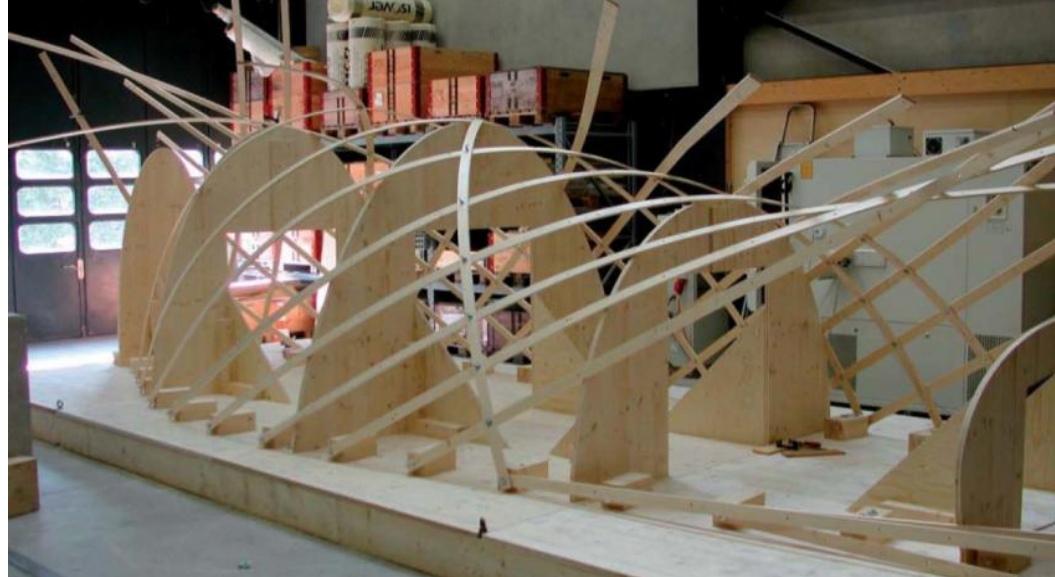
Construction detail



GEOS

Build rib shells on free-form surfaces





Research

Structural behavior of rib shells

Develop a finite element

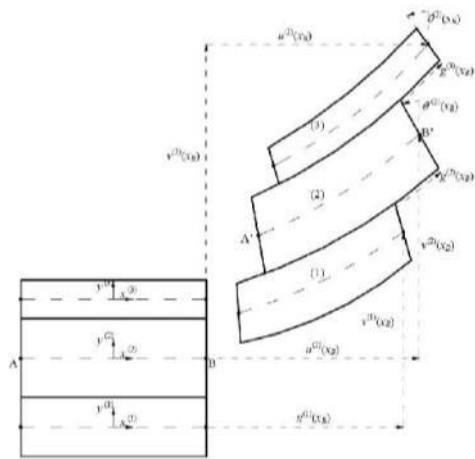
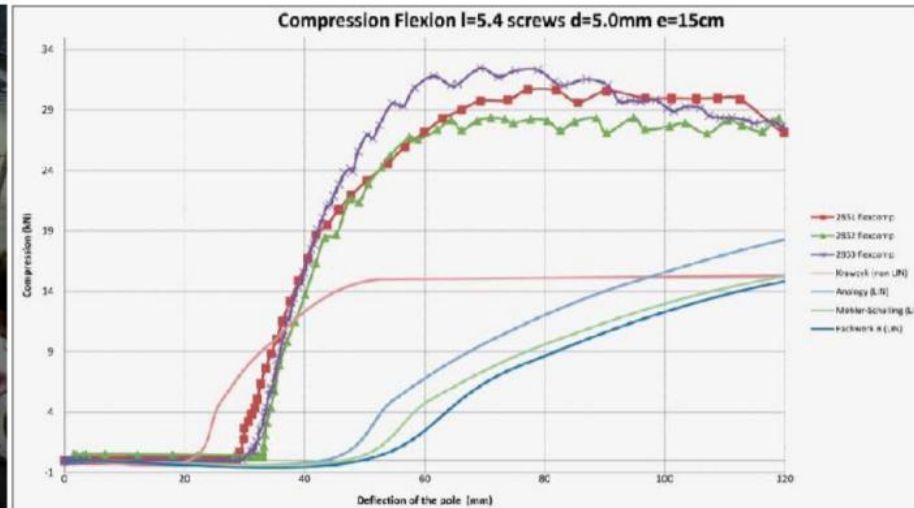
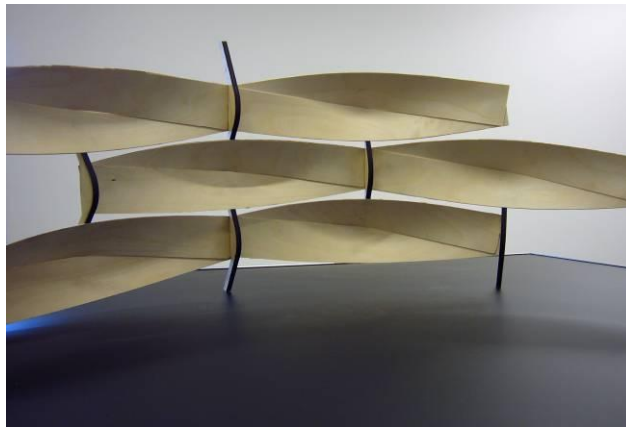
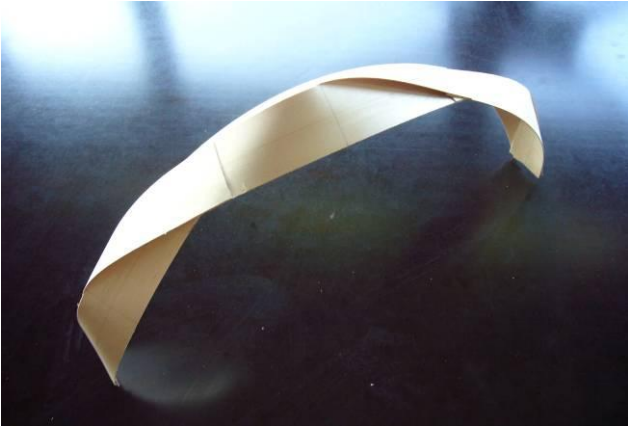


Figure 3 Kinematic relations for a multilayer beam with slips

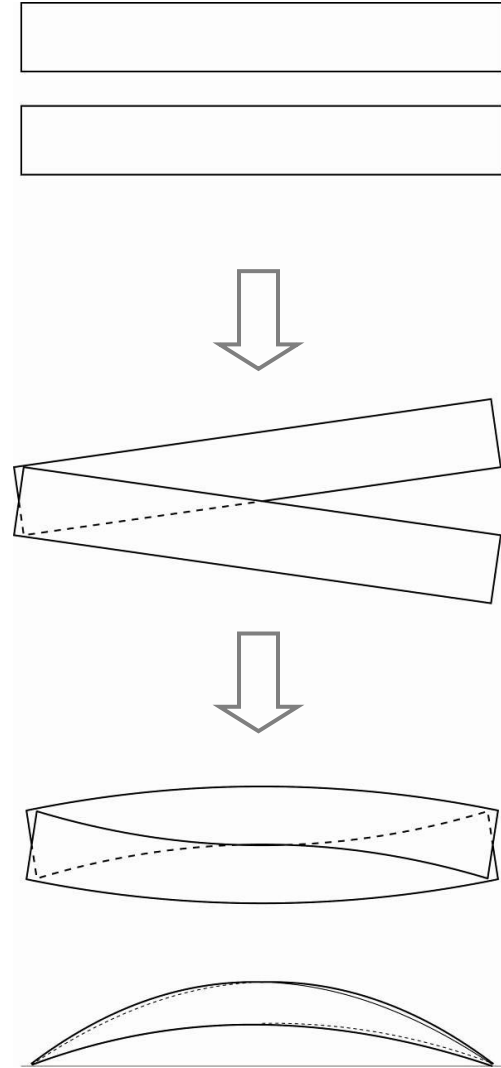


Structural timber fabric

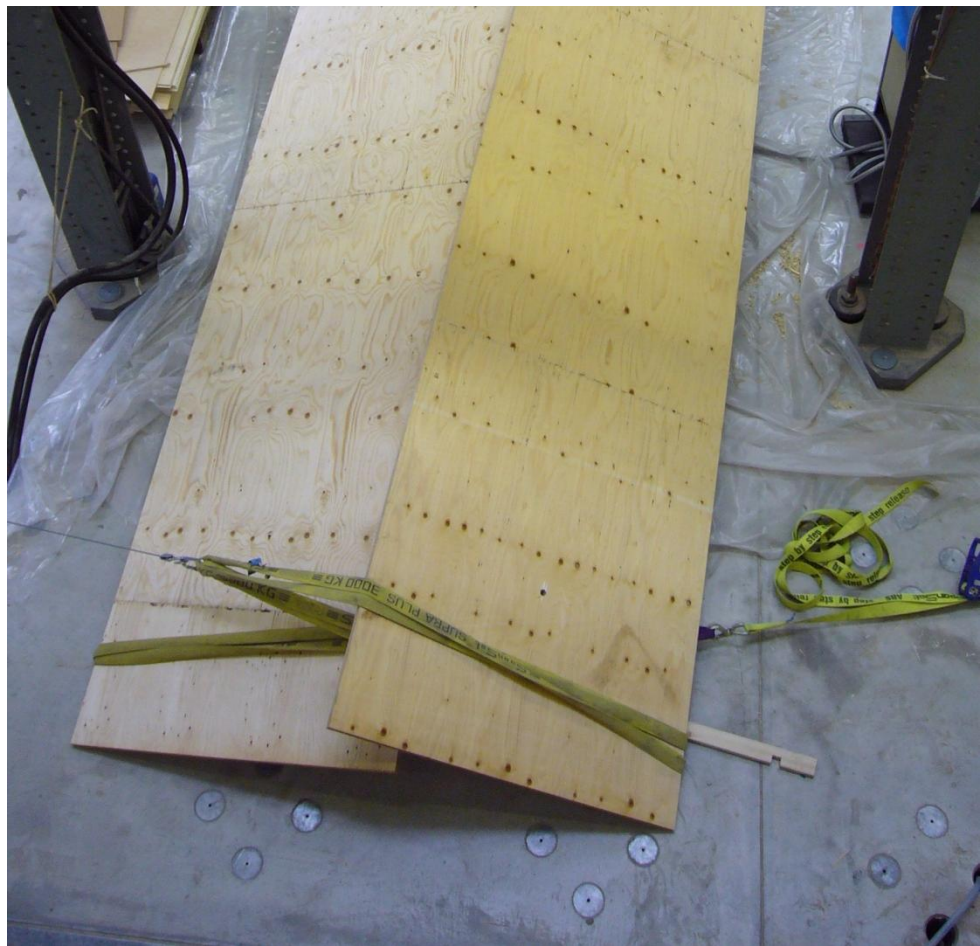
Applying textile principles to building scale



Linear Components



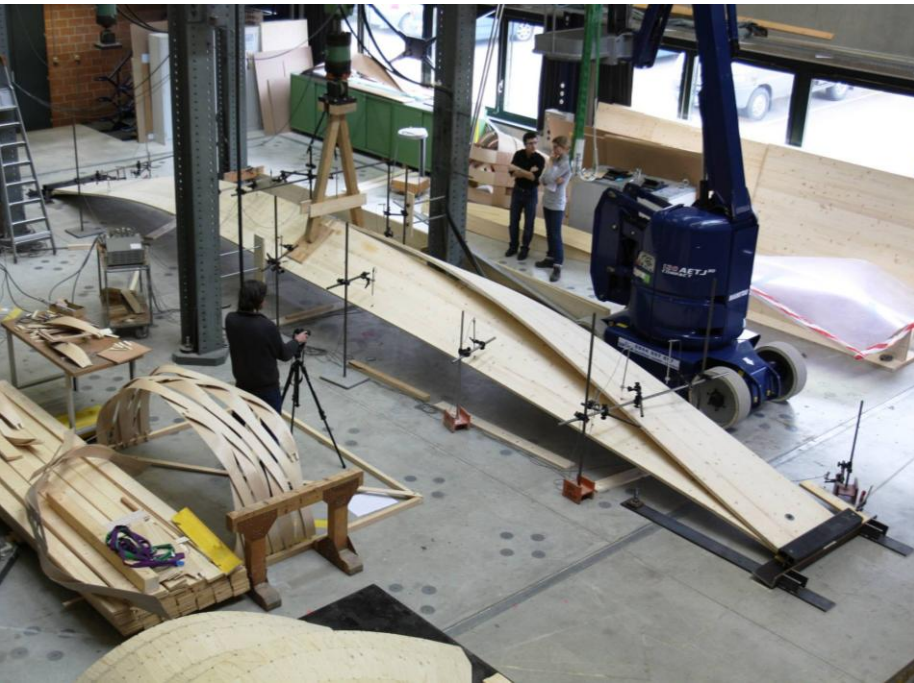
Research



Research

Markus Hudert

Linear Components

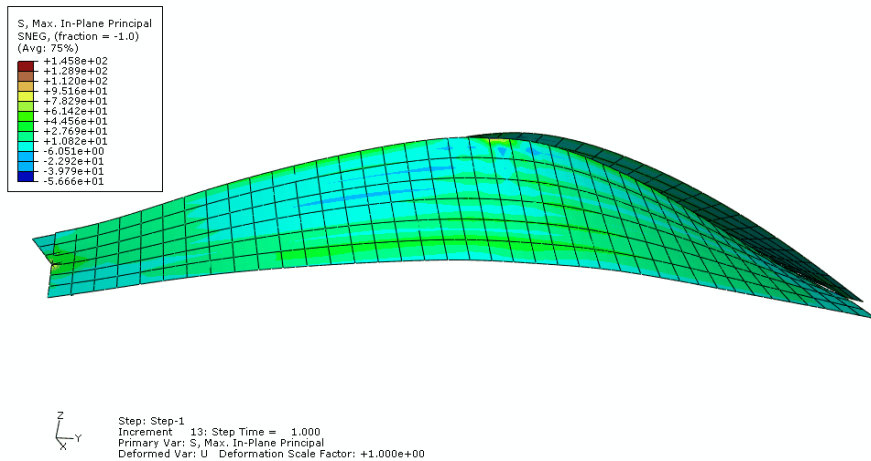


Research

Markus Hudert

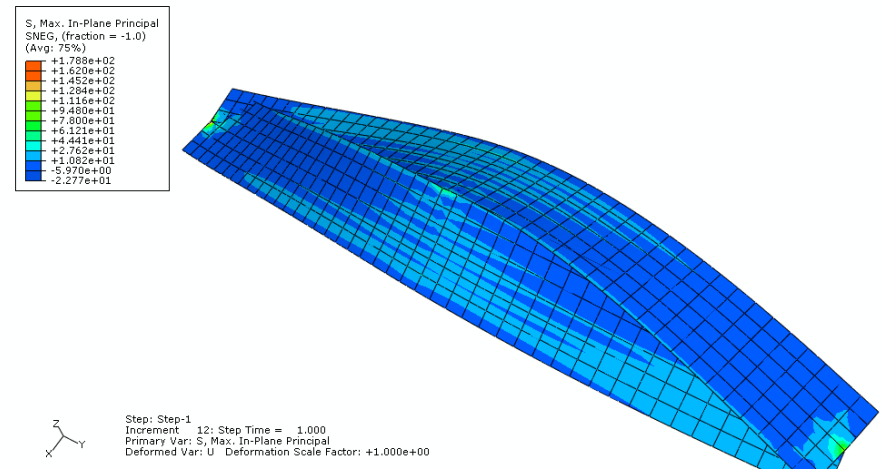
Maximum principal internal stresses for two proportion

Proportion (length/width)= 7
Length= 11.55 m, Width= 1.65 m



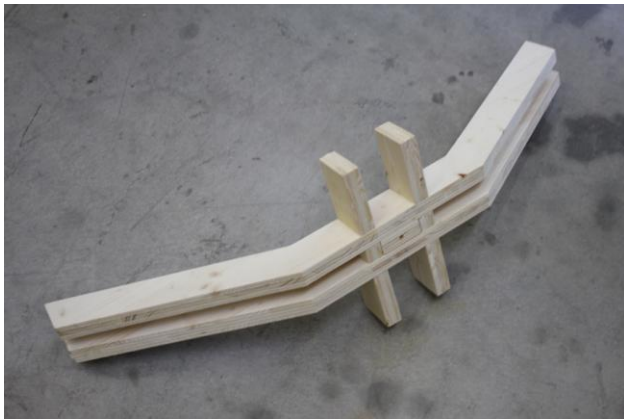
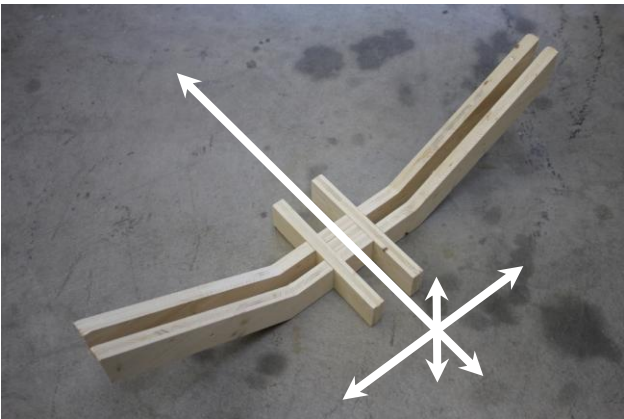
Maximum Principal stress= 46 MPa

Proportion (length/width)= 8.7
Length= 11.55 m, Width= 1.32 m



Maximum Principal stress= 29 MPa

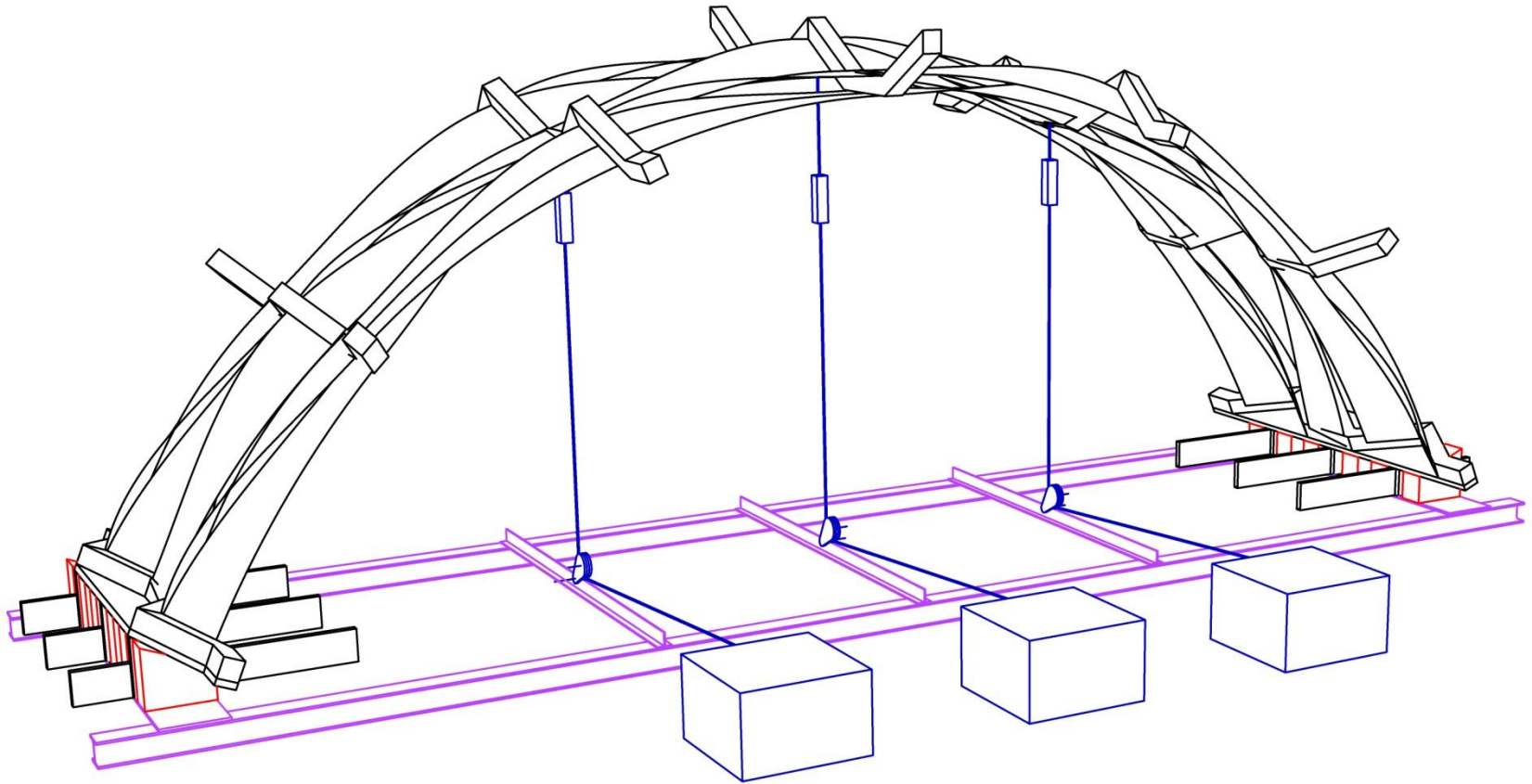




Research

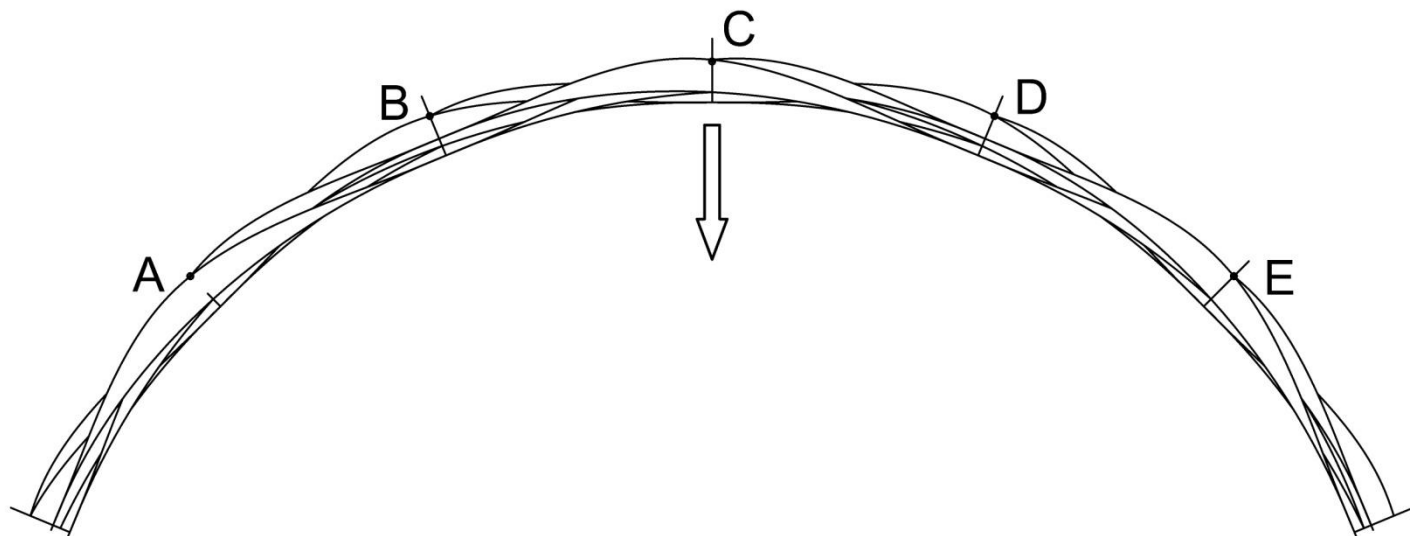
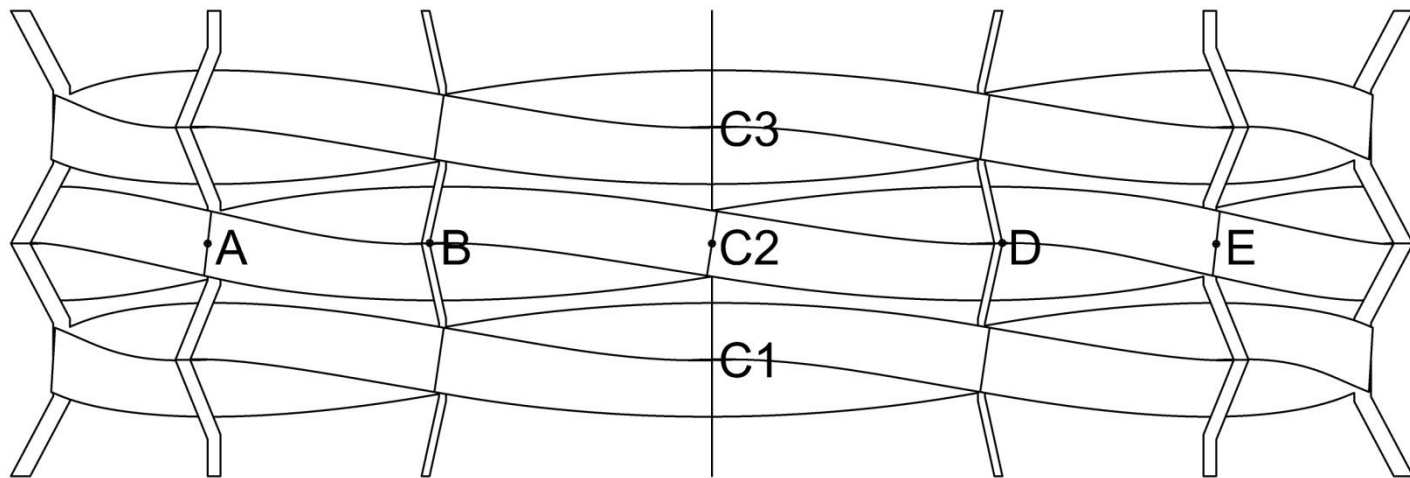


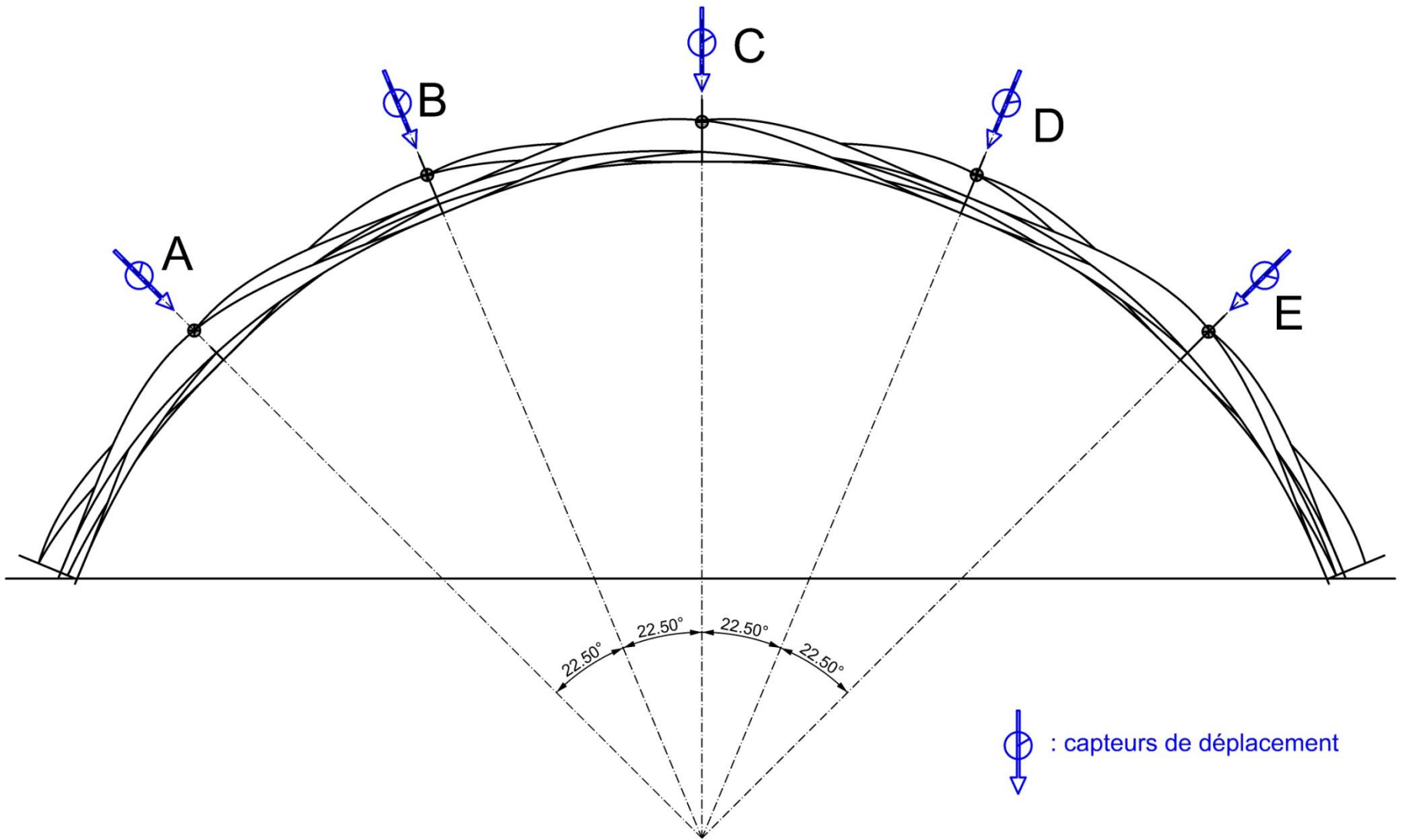
Research



Research

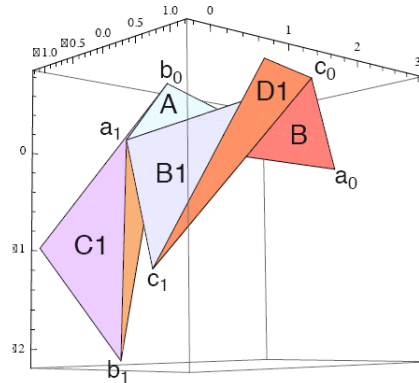
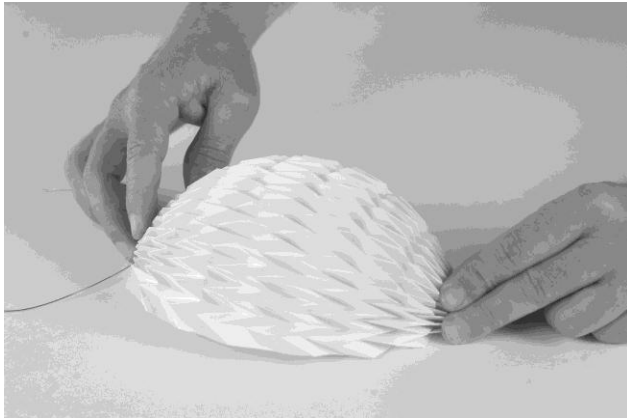
Timberfabric



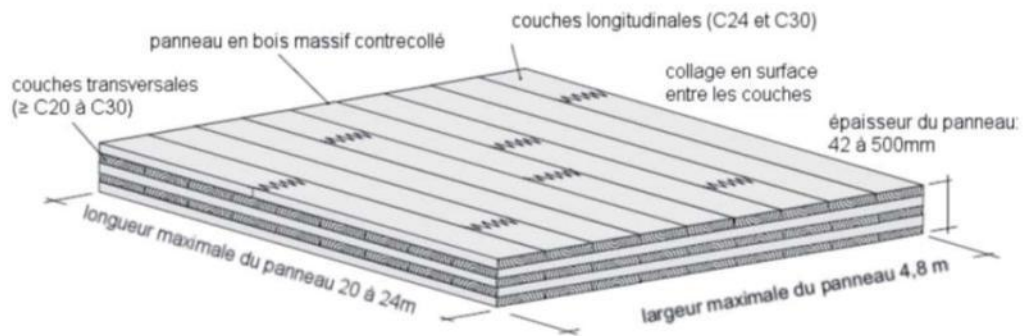
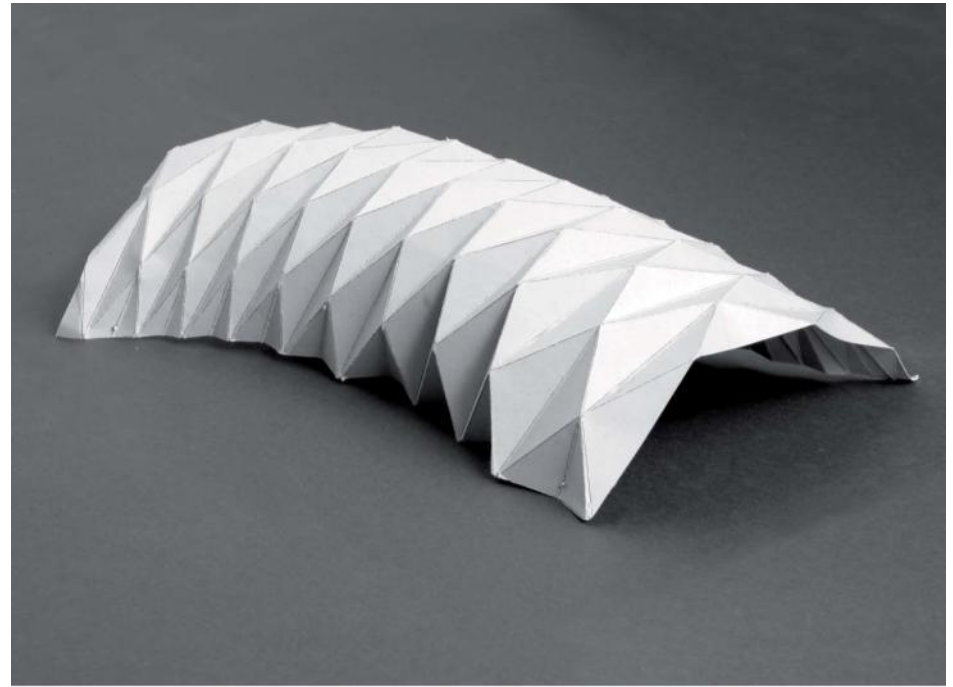
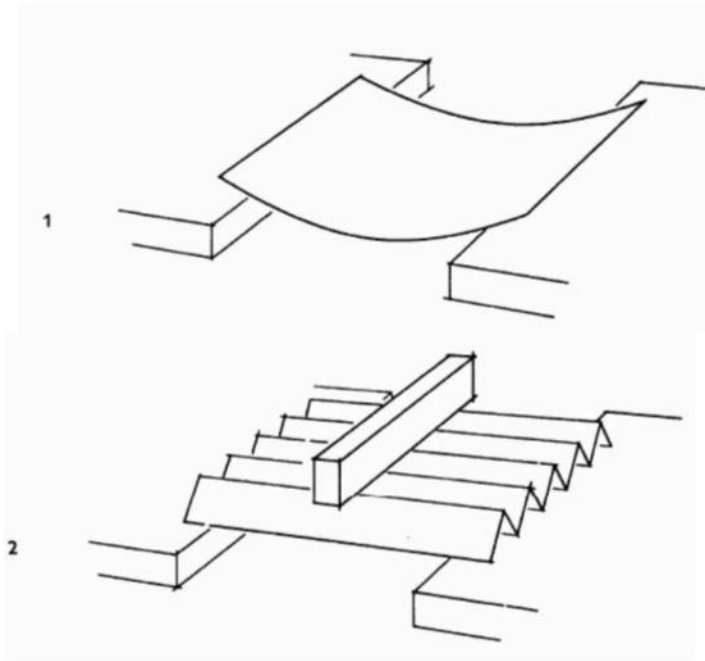


Origami – Folded Plate

An interdisciplinary reasearch between architects , engineers and mathematiens



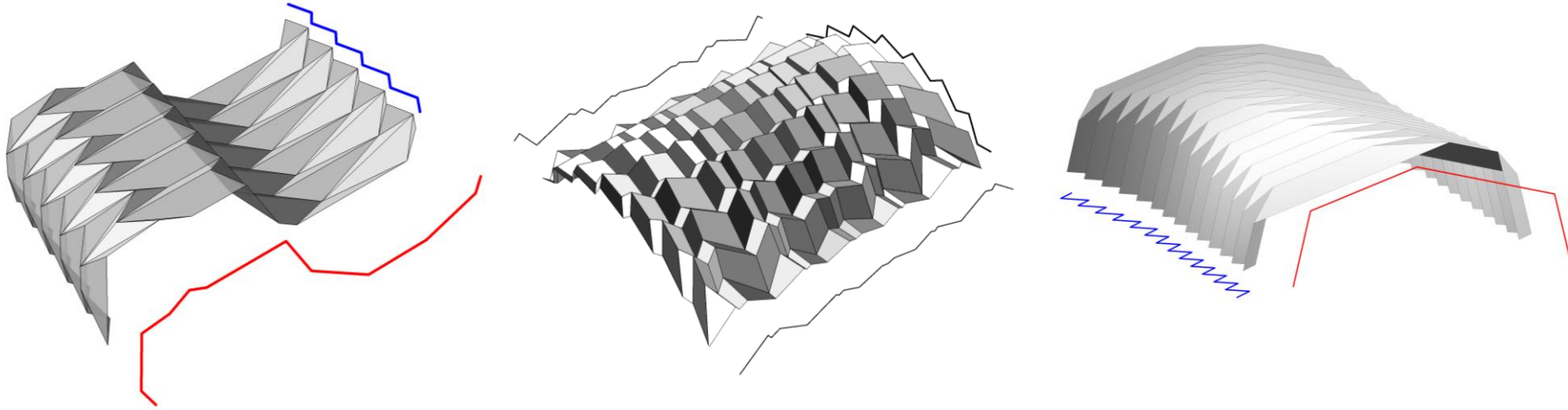
Surface Components



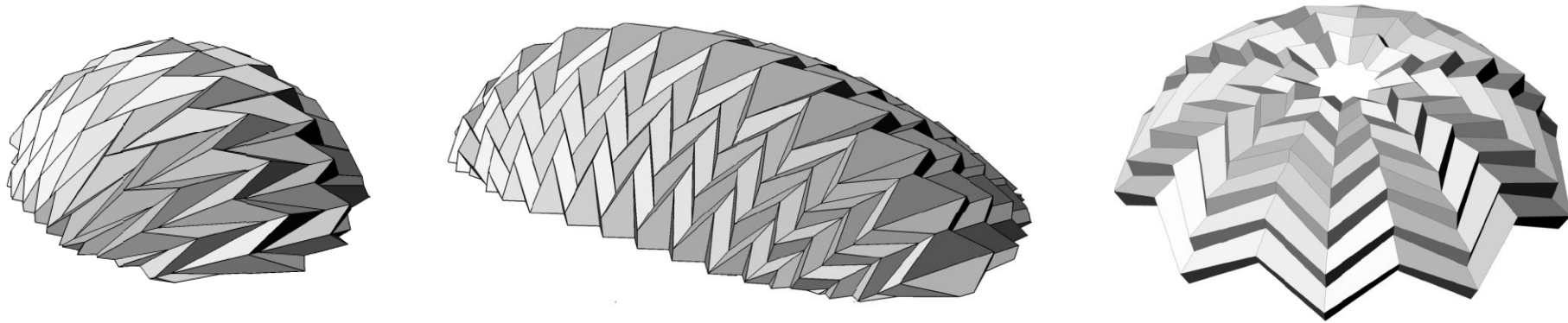
Research

Digital modeling

single patch geometries



multi patch geometries

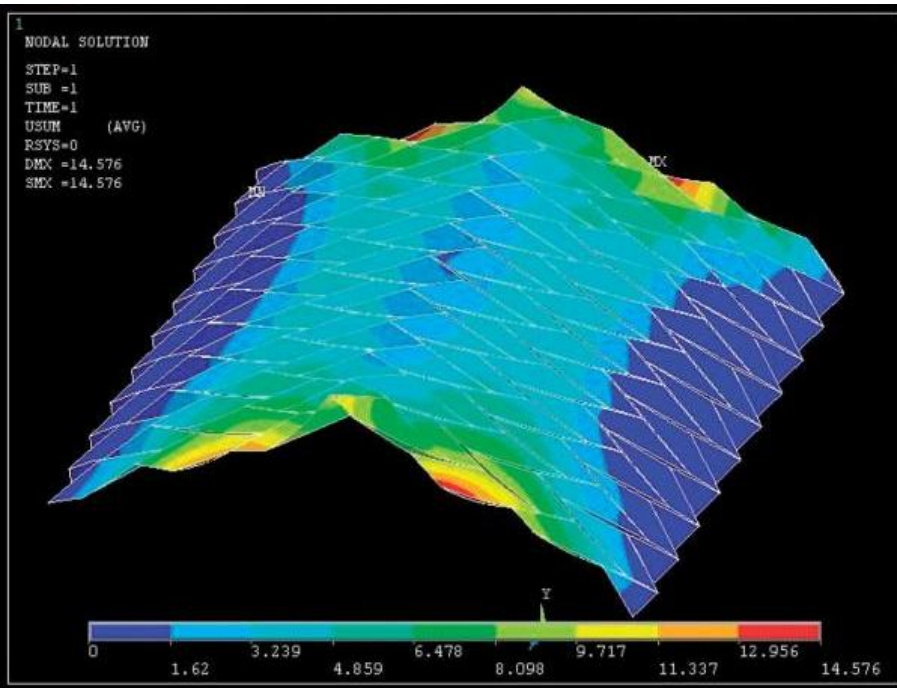


Prototype



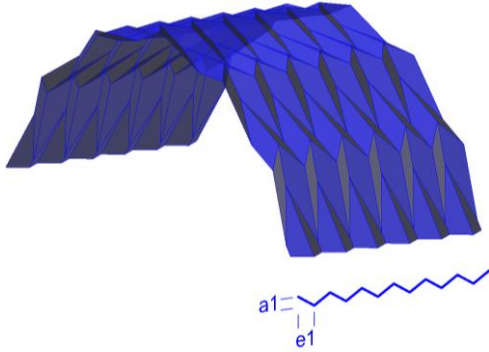
Engineering

Both numerical simulation and laboratory testing contribute important information

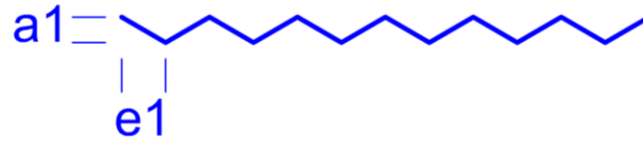


Geometry

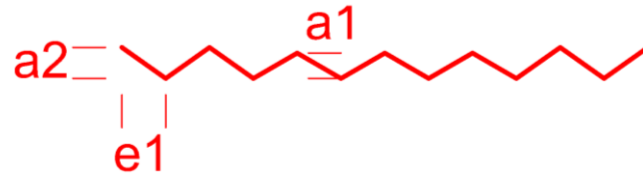
Deformations



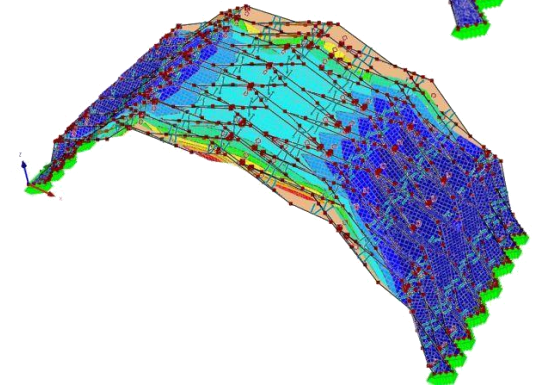
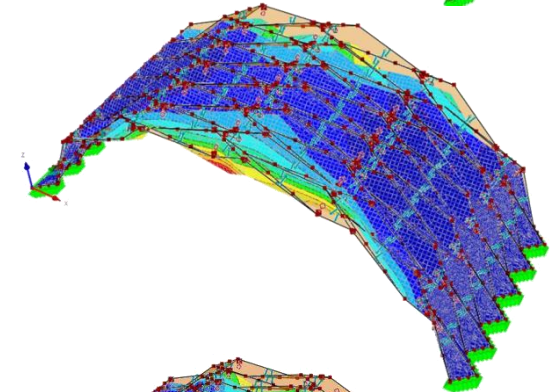
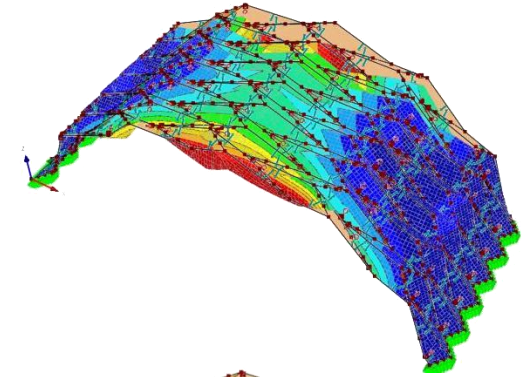
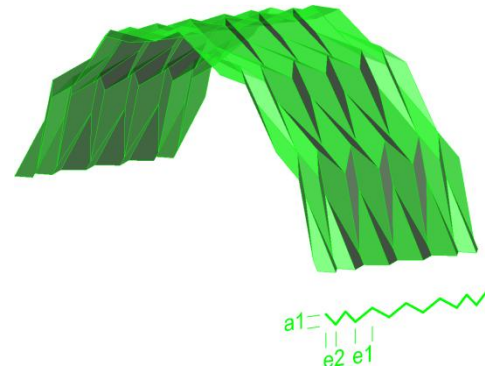
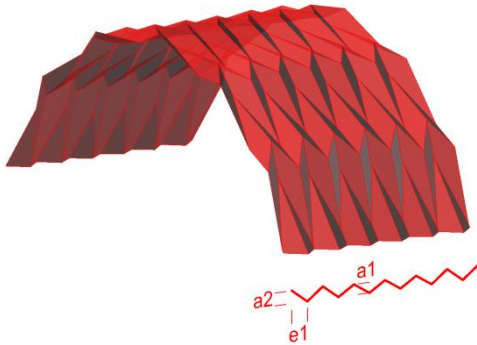
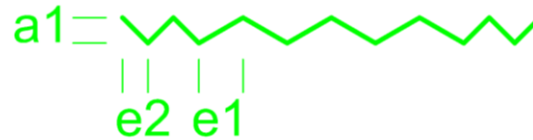
1. Max vertical displacement
3.3 mm



2. Max vertical displacement
2.2 mm



3. Max vertical displacement
1.9 mm



Chapelle de St.Loup

MAITRE D'OUVRAGE

INSTITUTION DES DIACONESSES DE ST-LOUP

MANDATAIRES

GROUPEMENT D'ARCHITECTES

LOCALARCHITECTURE

BUREAU D'ARCHITECTURE DANILO MONDADA

SHEL

Hani Buri, Yves Weinand

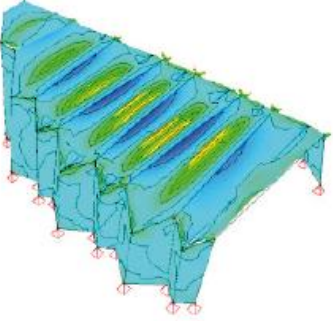
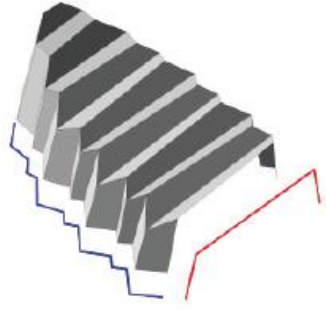
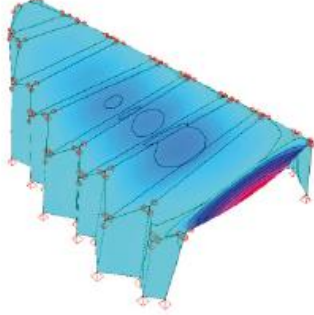
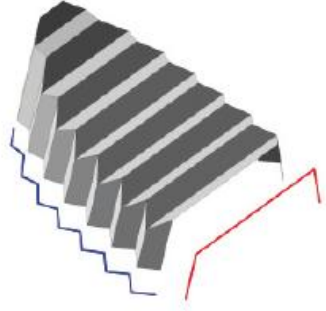
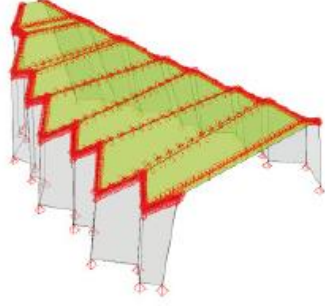
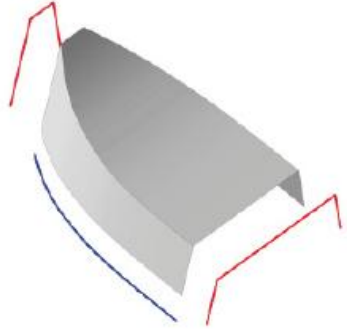
ARCHITECTURE, ENGINEERING AND PRODUCTION DESIGN

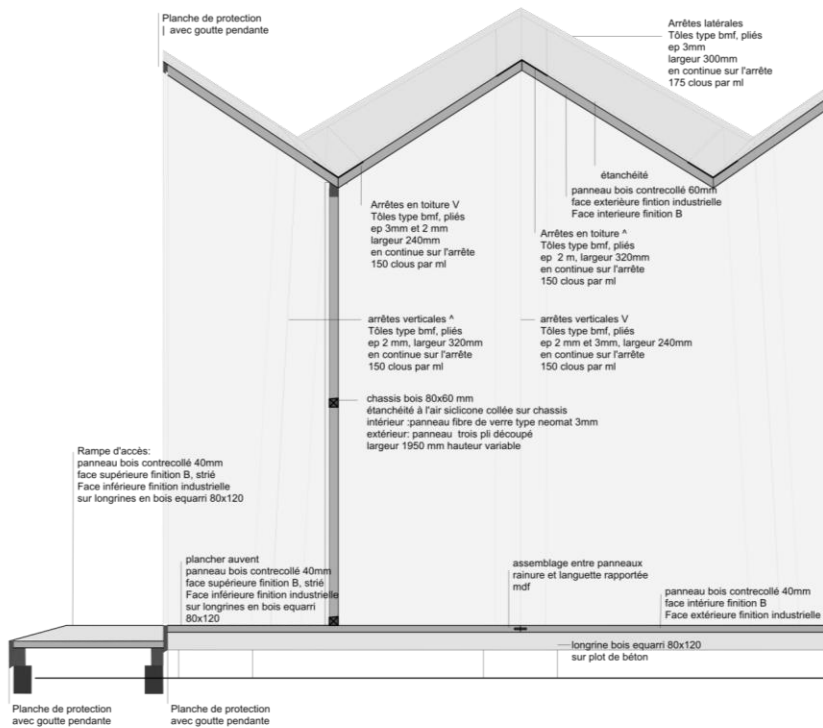
Une start-up de l'EPFL IBOIS

SOUTIEN FINANCIER

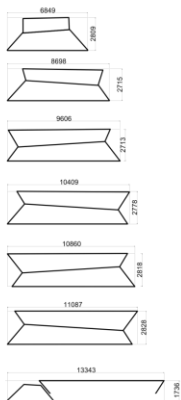
Office fédéral de l'environnement OFEV



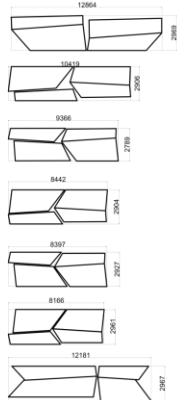




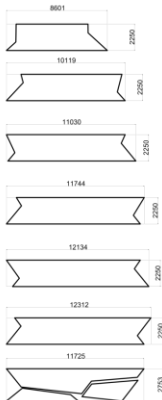
panneaux de toiture 60mm 151m2 net



panneaux verticales 40mm 175m2 net

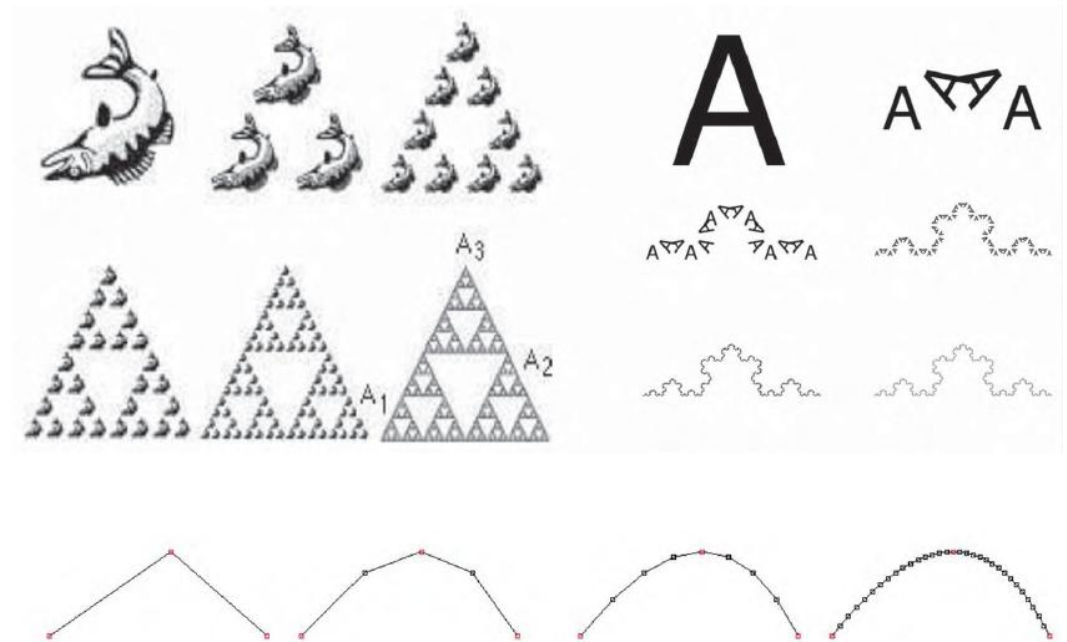
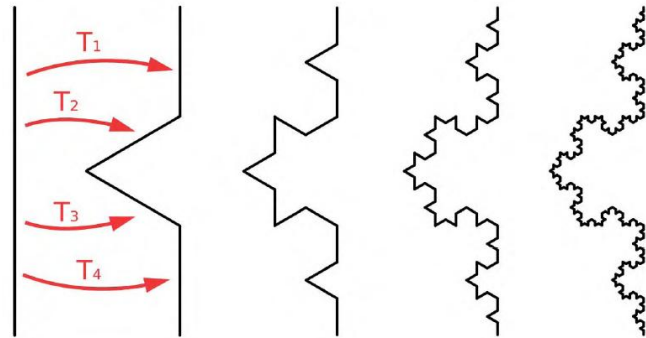
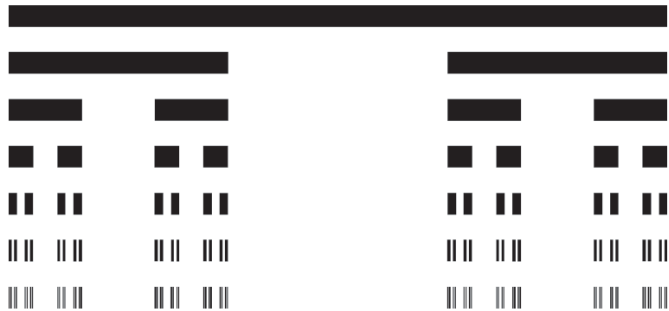


panneaux de plancher 40mm 155m2 net



Mathematical Background

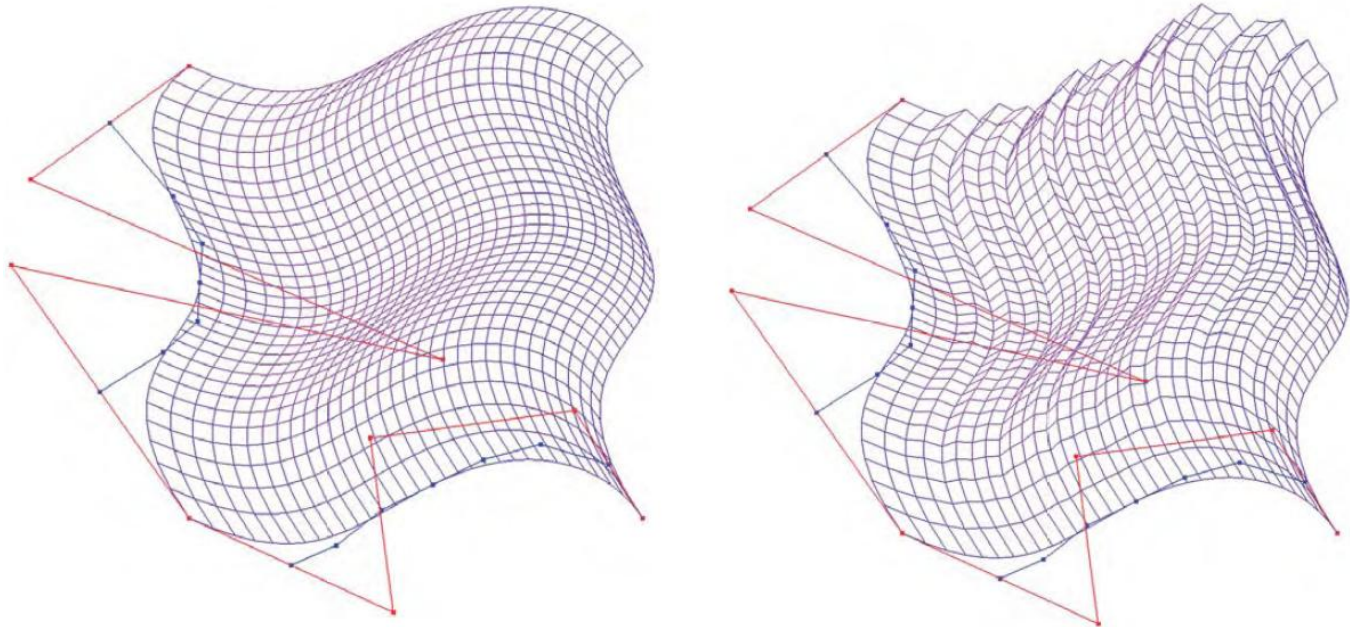
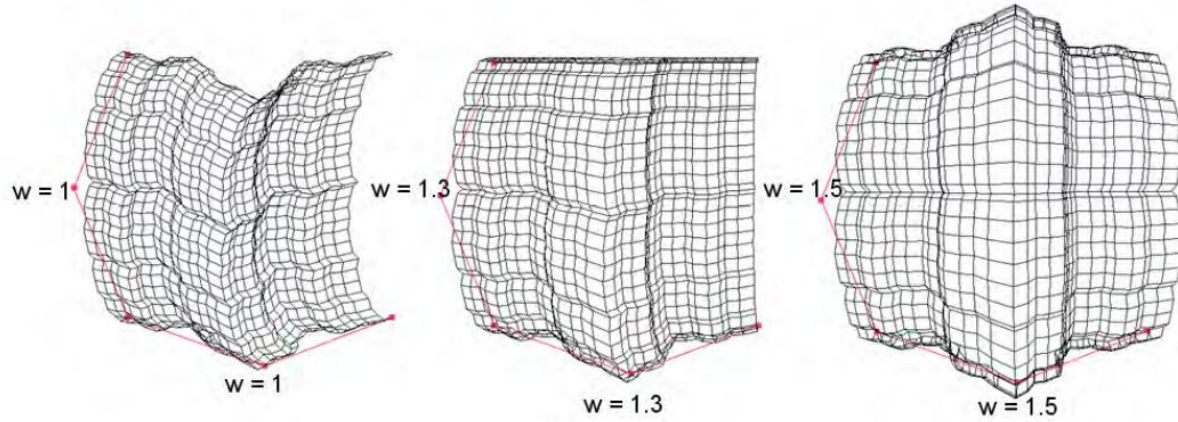
Of monster curves and iterative geometric figures



Research

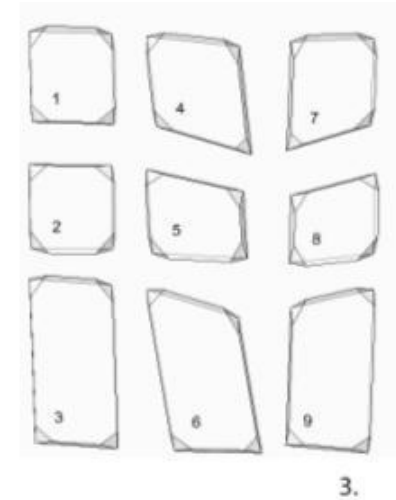
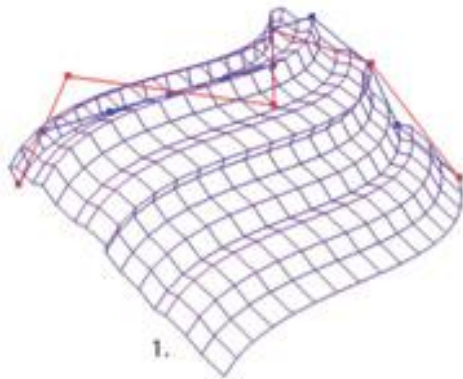
Iterative Surface Method

A new surface model



Integrated Design and Production

Computer-aided solutions for the production of complex free-form architecture



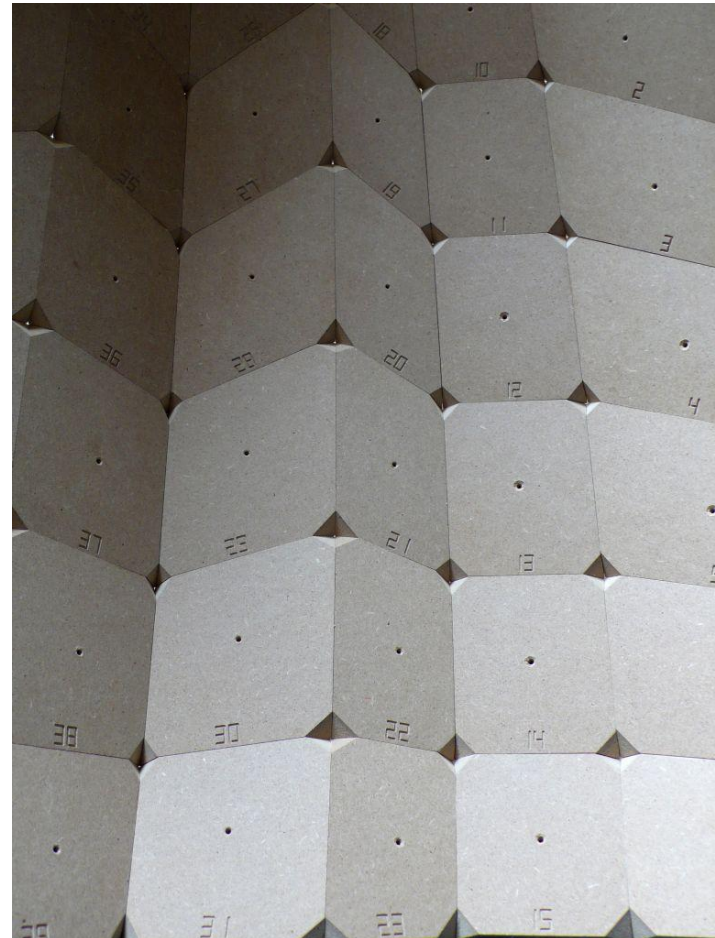
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N2 G71 T1 M6
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N4 G1 Z-3
N5 G1 X92.5173637881376 Y32.3964638989584
N6 G1 Z6
N7 G0 X108.361877416248 Y60.3013778158484
N8 G1 Z-3
N9 G1 X107.858915143915 Y30.1236414758803
N10 G1 Z6
N11 G0 X96.8557138994148 Y62.005994633157
N12 G1 Z-3
N13 G1 X96.352751627082 Y31.8282582931889
N14 G1 Z6
N15 G0 X104.526489577304 Y60.8695834216179
N16 G1 Z-3
N17 G1 X104.023527304971 Y30.6918470816498
N18 G1 Z6
```



Digital production of free-form architecture

1. Free Surface design
2. Computing the constructional elements
3. Addressing and lay out of the elements
4. Machine code generation
5. Integrated manufacturing

Feasibility study: 8x8 Prototype



Research



IBOIS - Laboratory for timber constructions

head

Prof. Yves Weinand, ISA architect, EPFL civil engineer

administration

Hildegard Bachmann, secretary

staff

Dr. Hani Buri, EPFL architect, scientific collaborator

Dr. Laurent Humbert, mechanical engineer Poitiers, scientific collaborator

Dr. Bernhard Stamm, civil engineer, Karlsruhe (D), scientist

Dr. Ivo Stotz, EPFL architect, scientist

François Demoures, EPFL mathematician, PhD assistant

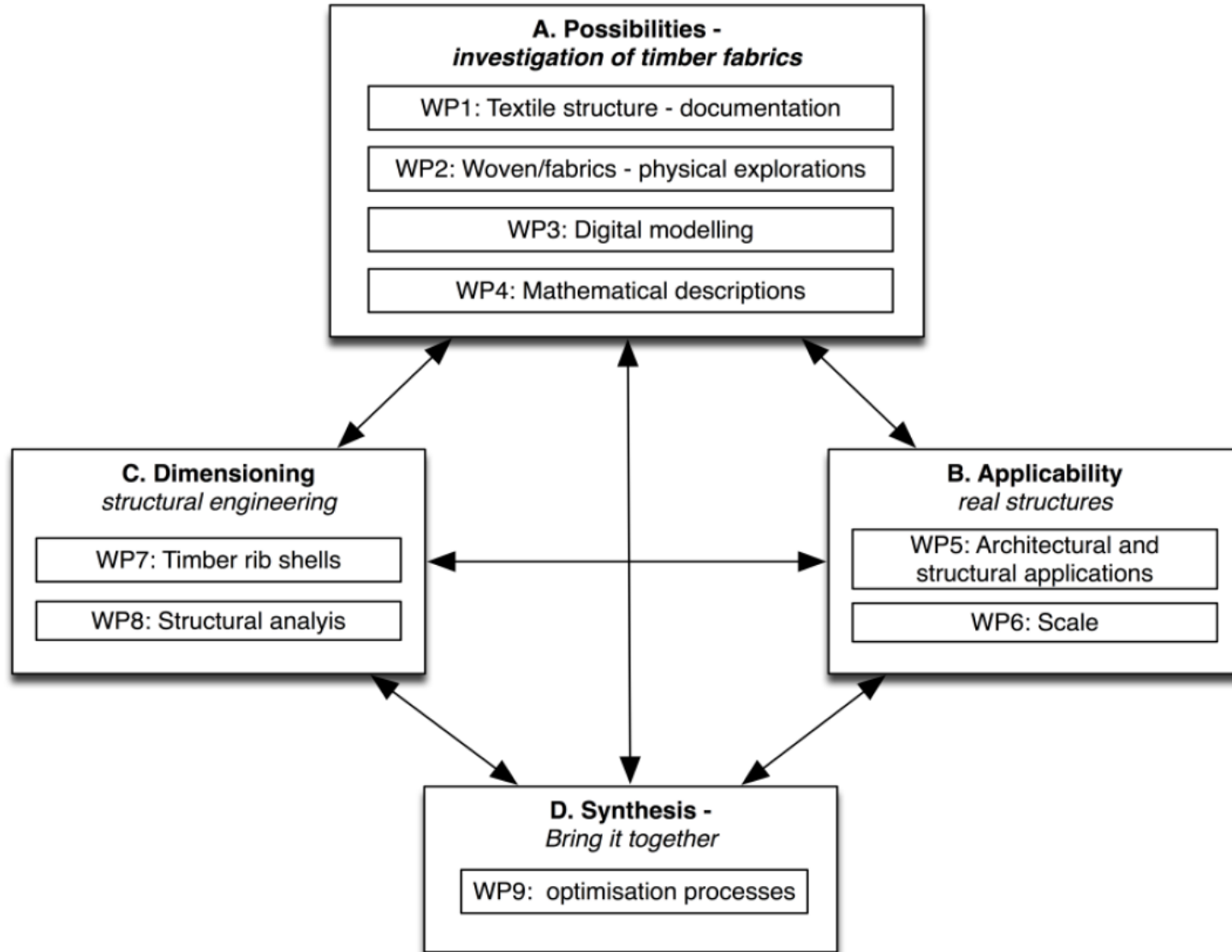
Markus Hudert, Städelsschule Frankfurt (D) architect, PhD assistant

Benjamin Hahn, civil engineer, ESTP Paris and TU Dresden, PHD assistant

Sina Nabaei, structural engineer, ENPC Paris, PHD assistant

Christopher Robeller, architect, London Metropolitan University, PHD assistant





Curved Origami

Bending timber panels

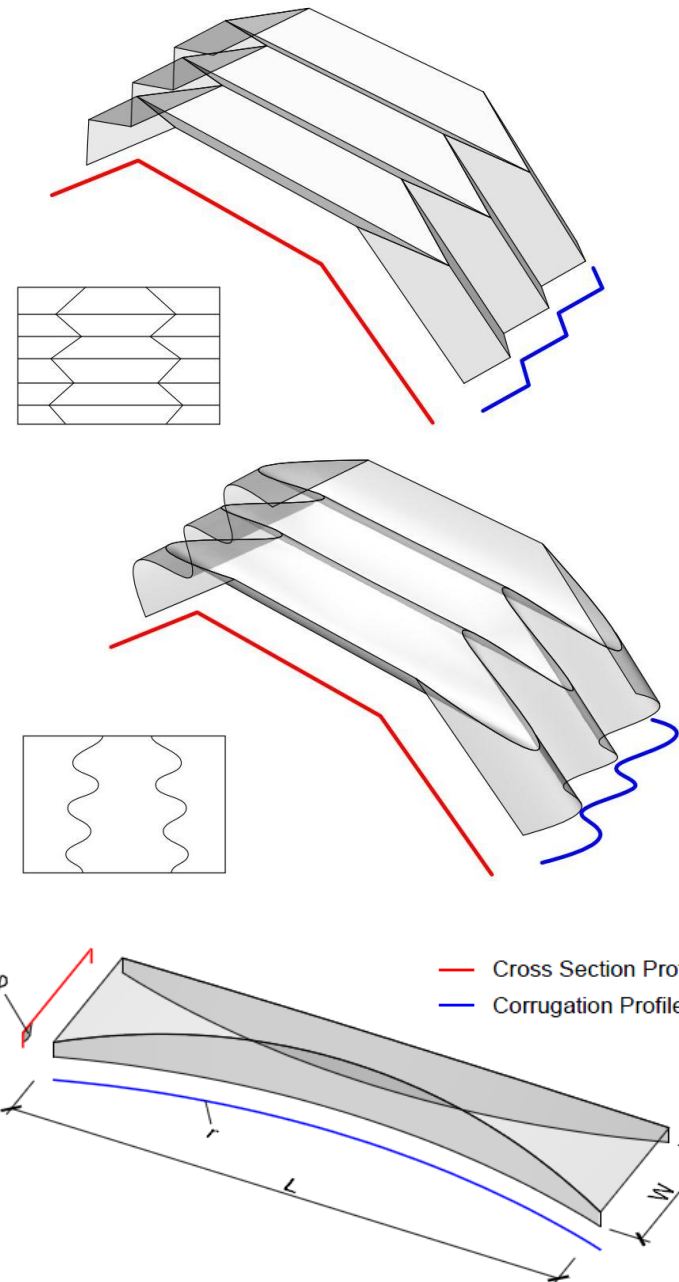
Design of light-weight large span structures

Geometric design using curved corrugation profile instead of a straight polyline

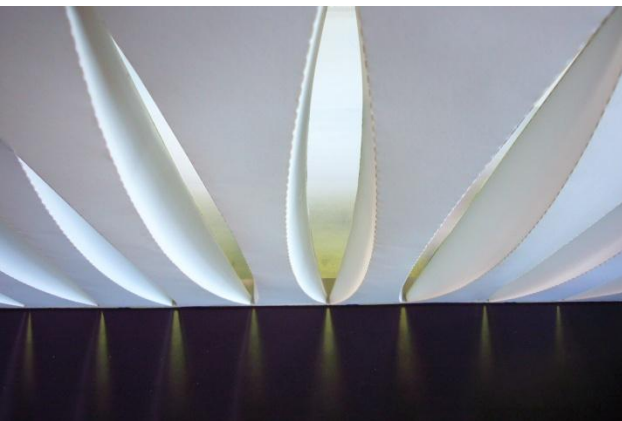
Research in constructive detailing for joining and assembly

Research in structural optimisation by load tests and FE-analysis

Applications



Curved Origami Prototypes and Applications



Research

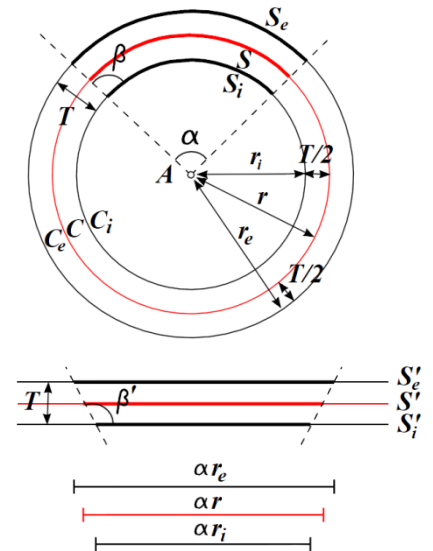
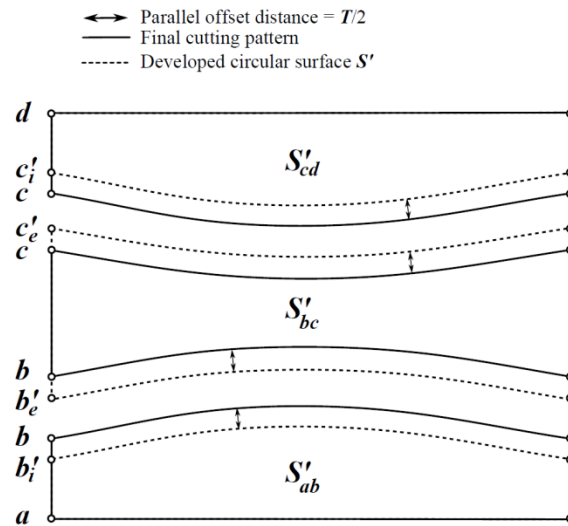
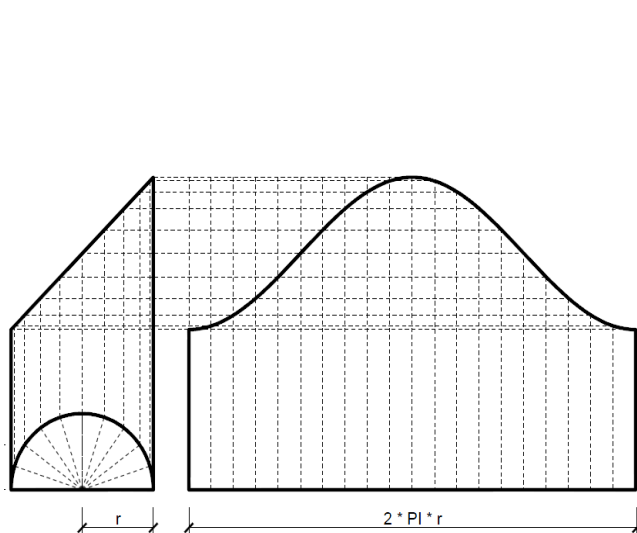
Curved Origami

Geometry and Detailing

Unrolling of the curved surfaces

Multilayer Geometry

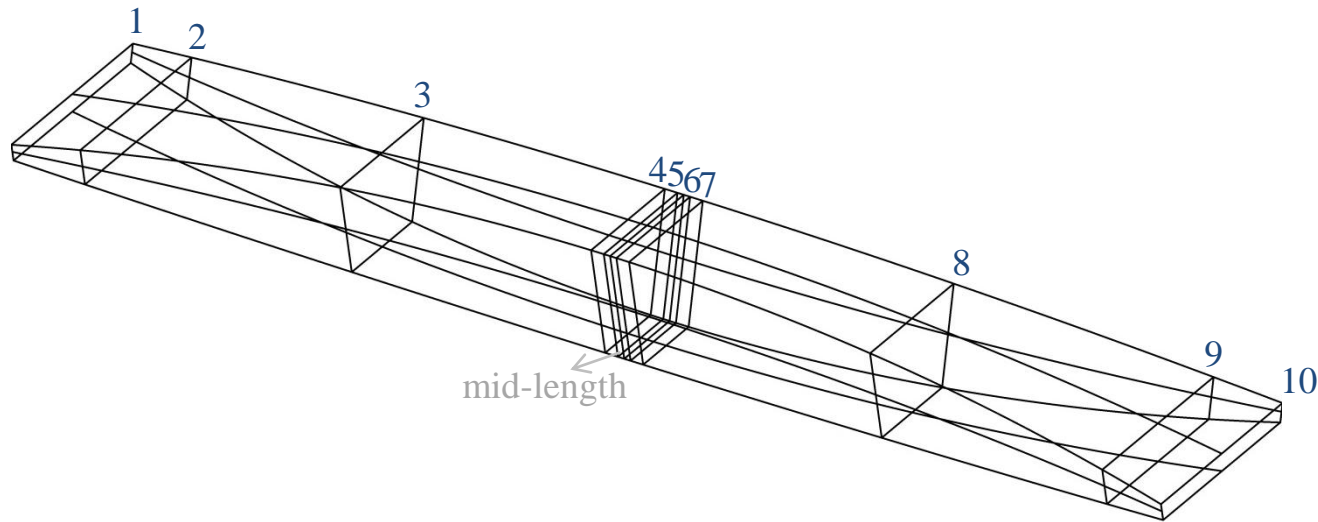
Constructive Detailing



Experimental investigation

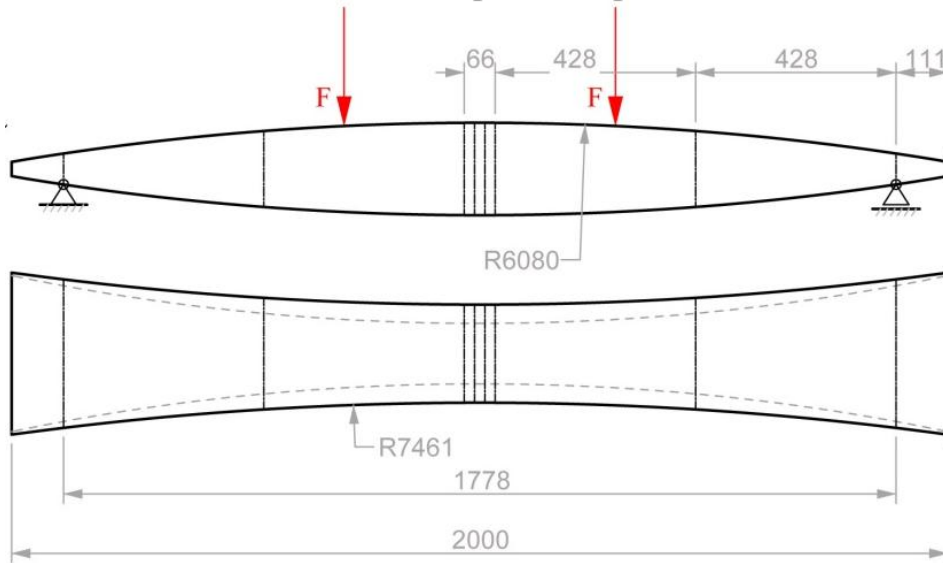
Prototypes:

- Curved prototypes of length $2m$:



- Okoumé plywood panels (three plies) of thickness $t = 6 \text{ mm}$
- 10 Stiffeners - Okoumé plywood of thickness 22 mm :
 - 4-5-6-7 linked together
 - 2, 9 placed at support position
- Screwed and glued connection between the panels

mid-surfaces of stiffeners and panels depicted



$$L = 2000 \text{ mm}$$

$$S = 1778 \text{ mm}$$

$$h_0 = 33.33 \text{ mm}$$

$$w_0 = 340.71 \text{ mm}$$

$$h_2 = 200 \text{ mm}$$

$$w_2 = 170.59 \text{ mm}$$

Parameters values:

$$i = 1.1249$$

$$q = 0.166$$

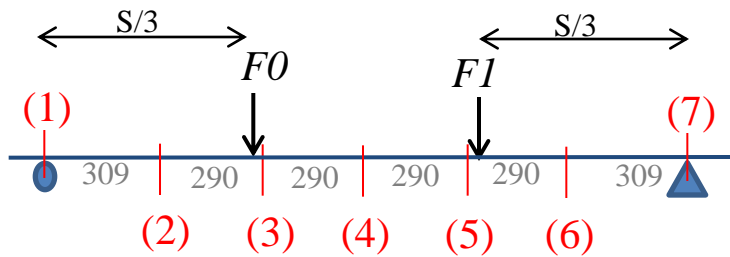
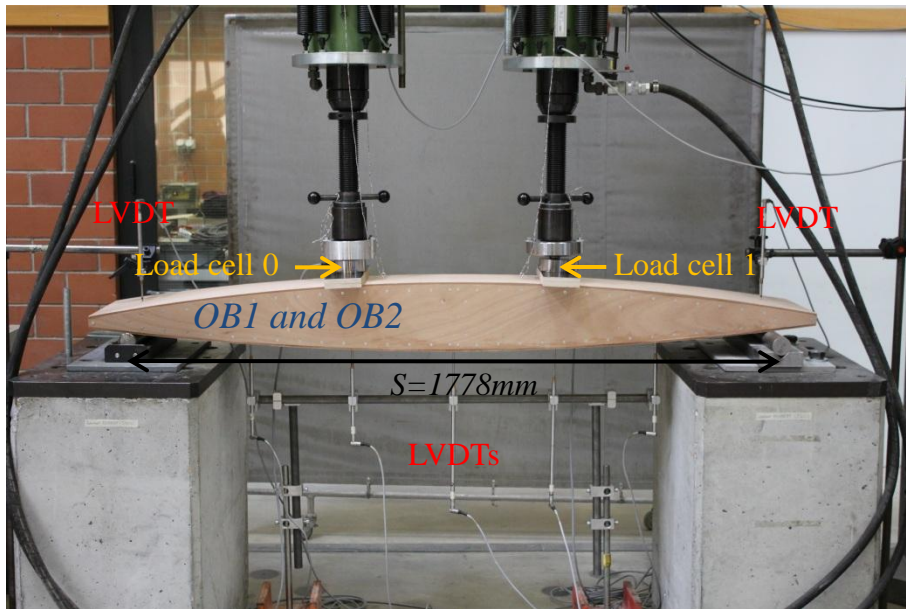
$$p = 1.172$$

$$\varphi = 78^\circ 44'$$

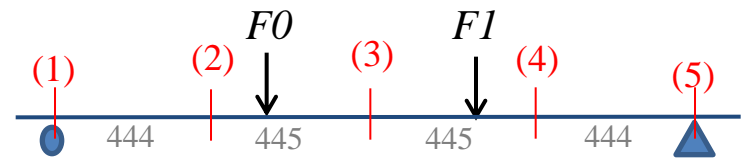
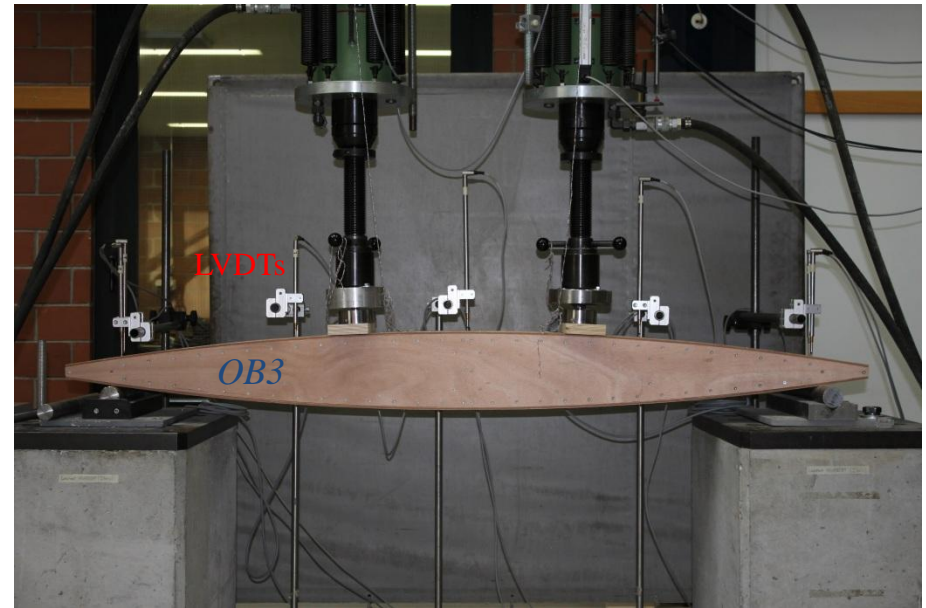
$$k = 0.208$$

Experimental setup:

Four point bending test : W+B 300kN loading system
three specimens *OB1*, *OB2*, *OB3*



transducers locations ($i=1..7$)

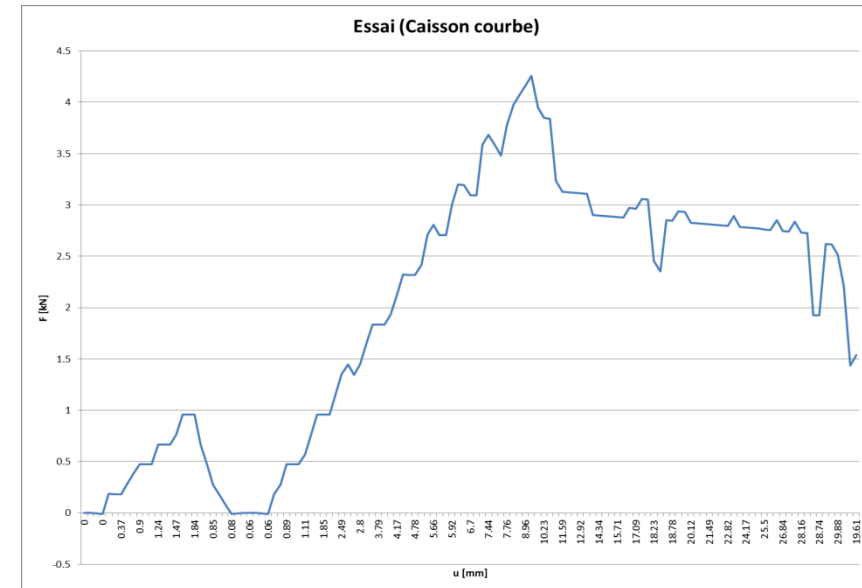
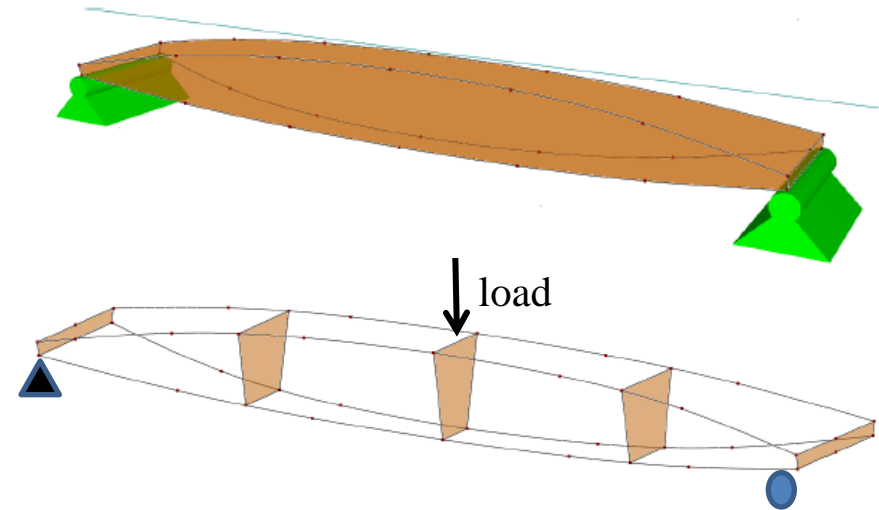


transducers locations ($i=1..5$)

Curved origami beams:



Students:
Yann CRETEGNY & Stefan SANDER



Research

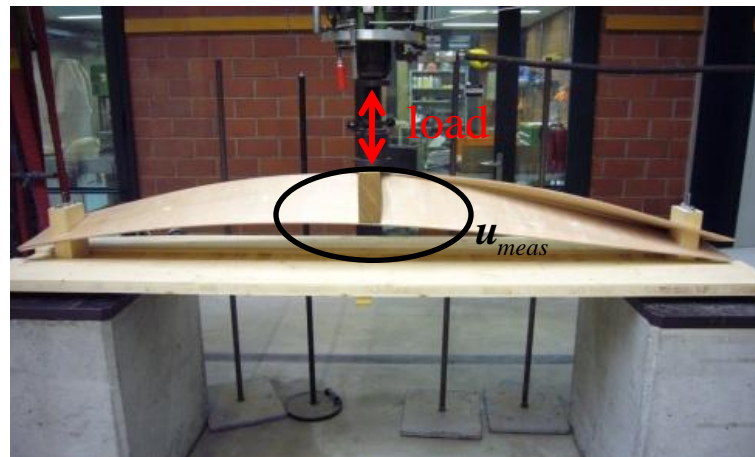
Laurent Humbert

Structural behavior of
innovative curved / folded
Timber structures



Numerical analysis

Doubly curved timber module :



↓
Experimental characterization

↓
Accurate 3D shape and surface
displacements u_{meas} measurement

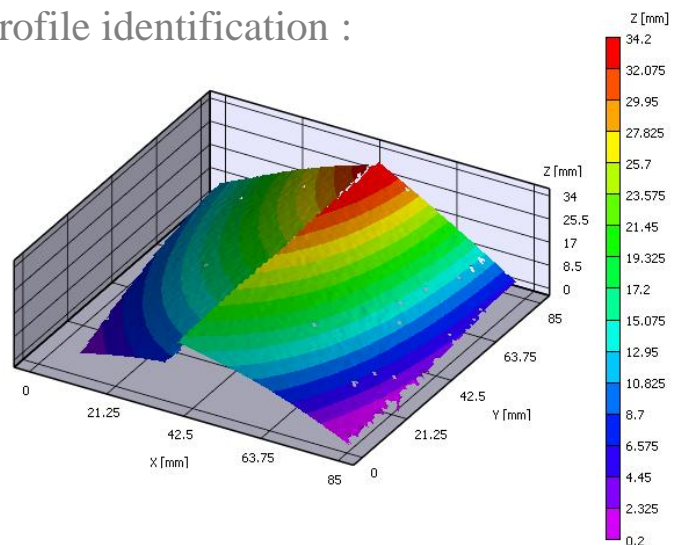
↓
Contactless optical method :
digital image correlation

10^{-2} pixel accuracy

non -intrusive

field measurements

Profile identification :

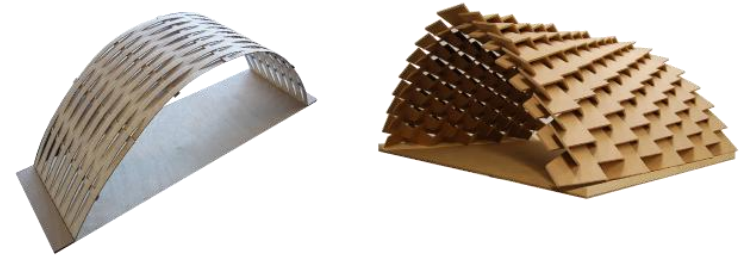


Future Research

Mechanical form-finding of the timber woven structures

Objectives:

- Predict the deformed configuration for a set of woven timber thin panels under an overall boundary condition
- Structural analysis and structural design



Challenges:

- Describe the mechanics of thin timber panels in finite deformation
- Collision detection (on side and faces of panels)
- Material orthotropic characteristics
- Numerical implementation



Relevant research fields:

- Micro and Meso mechanics of fibrous composites
- Real-time physics (Real-time deformable bodies, Collision detection algorithms)
- Dynamic relaxation method for form-finding of bending structures



A five step methodology for mechanical form-finding of woven structures

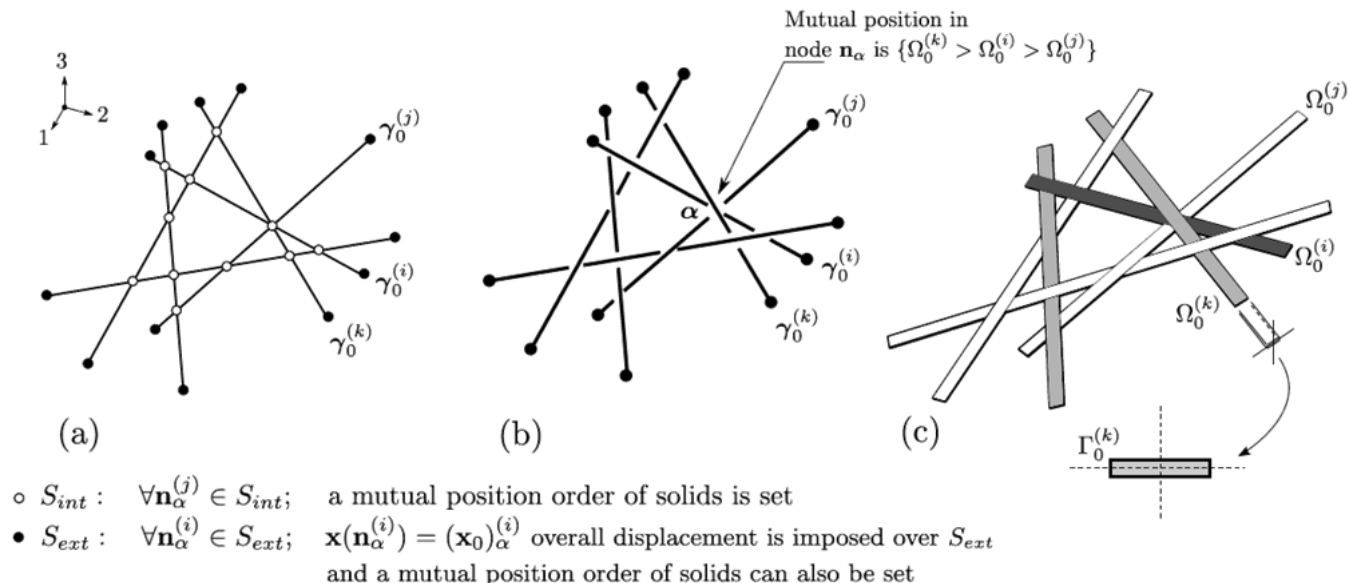
→ (i) Flat elementary configuration definition

→ (ii) Interaction definition

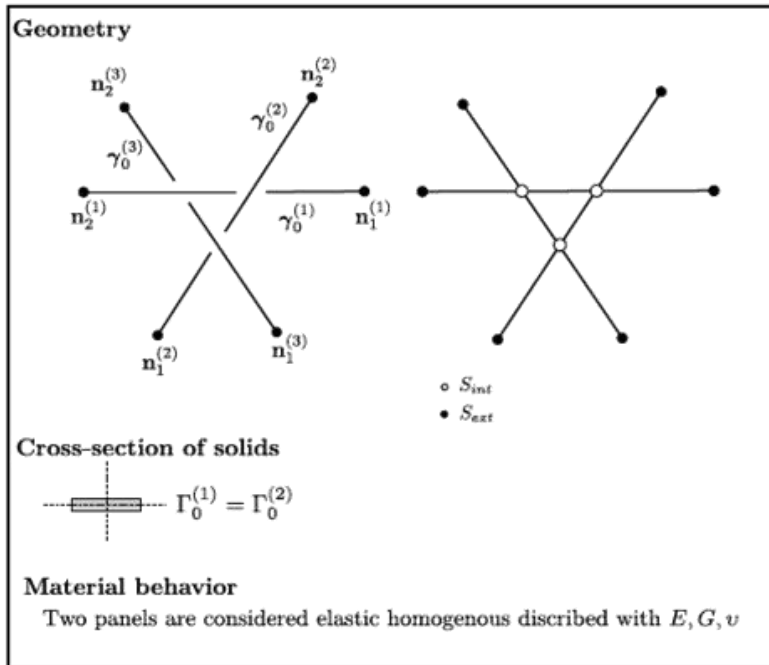
→ (iii) Imposing the boundary condition

→ (iv) Relaxation

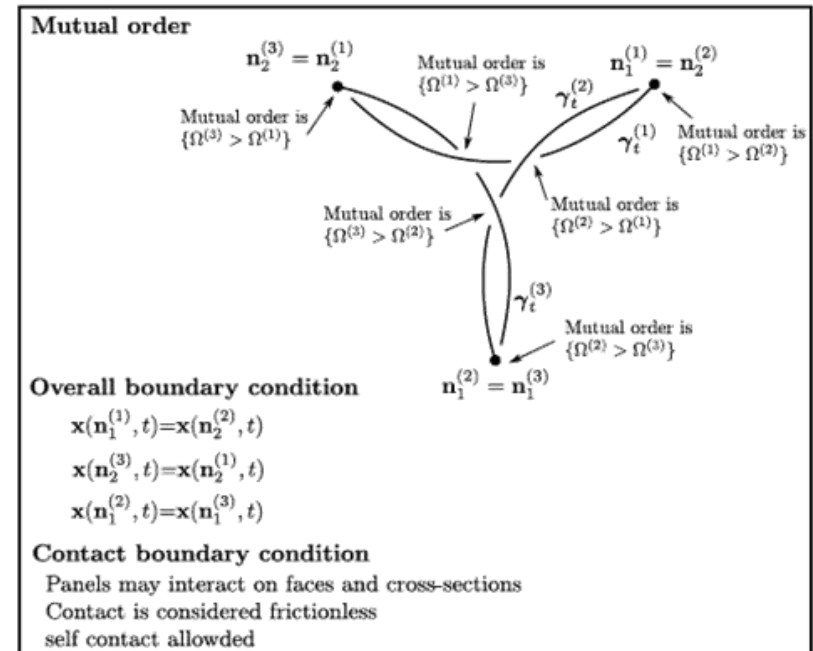
→ (v) Structural design



Methodology: example of application



Stp.1 Flat elementary configuration



Stps. 2-3 Definition and imposing boundary condition and mutual order



Stp.4 Relaxation



Friction Welding of Wood

*A new, adhesive free
bonding technology*

Resp.: Dr. Bernhard Stamm
PhD student Benjamin Hahn

Interdisciplinary Research Project:

„Sinergia Welding for Wood“

•BFH :

Bern University of Applied Science
Section Architecture, Wood and Civil Engineering
Biel (CH)

• LERMAB-ENSTIB:

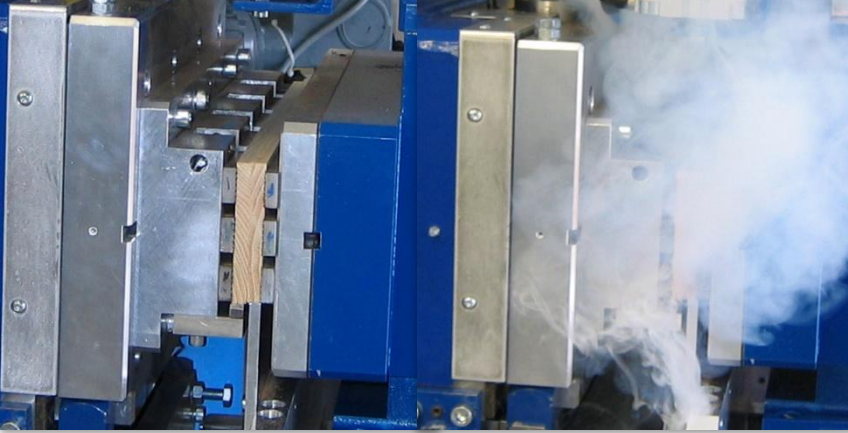
Ecole Nationale Supérieure des
Technologies
et Industries du Bois
Nancy (F)

• EMPA:

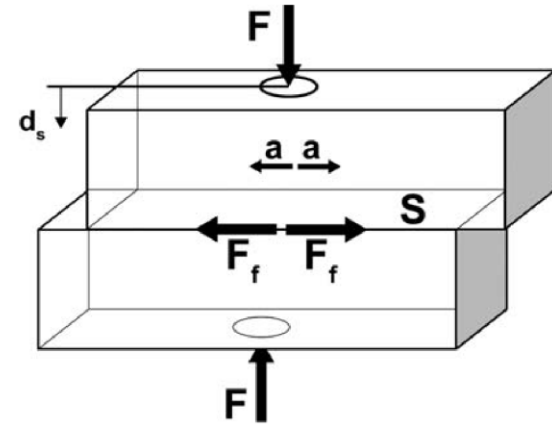
Swiss Federal Laboratories
for Materials Science and Technology
Wood Laboratory
Dübendorf (CH)

•EPFL:

Ecole Polytechnique Fédérale de Lausanne
Laboratory of wood construction IBOIS
Lausanne (CH)



Principle:



Welding parameters:

- Welding pressure: $1.0 \text{ Mpa} < P_s = F/S < 2.0 \text{ Mpa}$
- Frequency : $100 \text{ Hz} < f < 150 \text{ Hz}$
- Welding time: t_s / welding displacement: d_s
- Amplitude $1.5 \text{ mm} < a < 4.0 \text{ mm}$
- Friction force: $F_f = \mu \cdot F$

Structural applications:

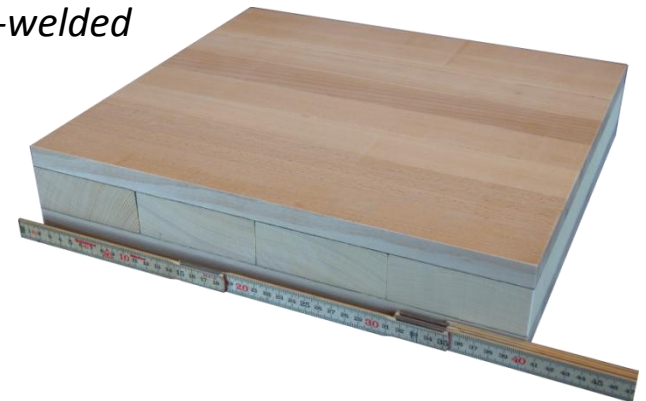
solid timber wall, floor and roof panels

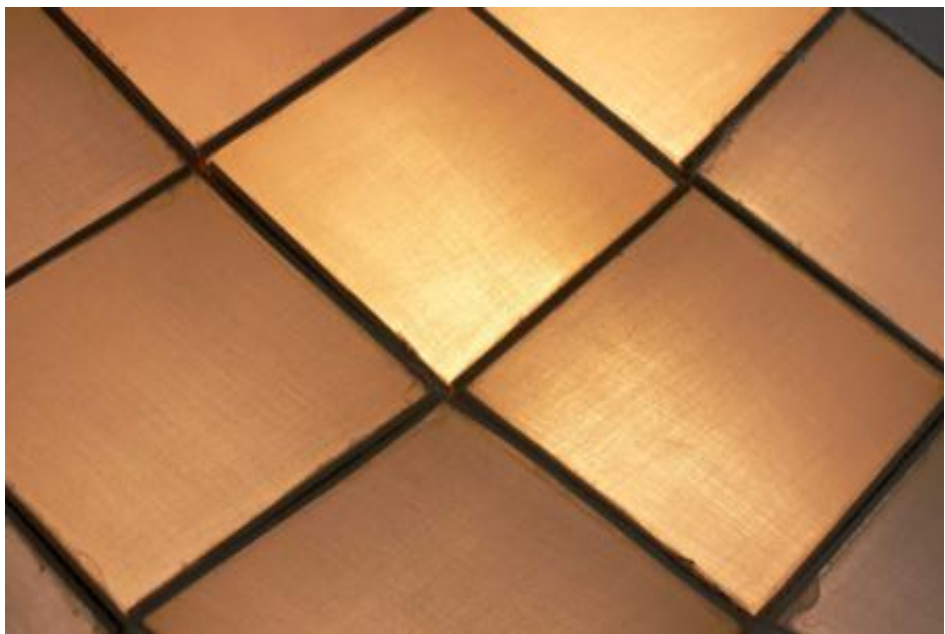
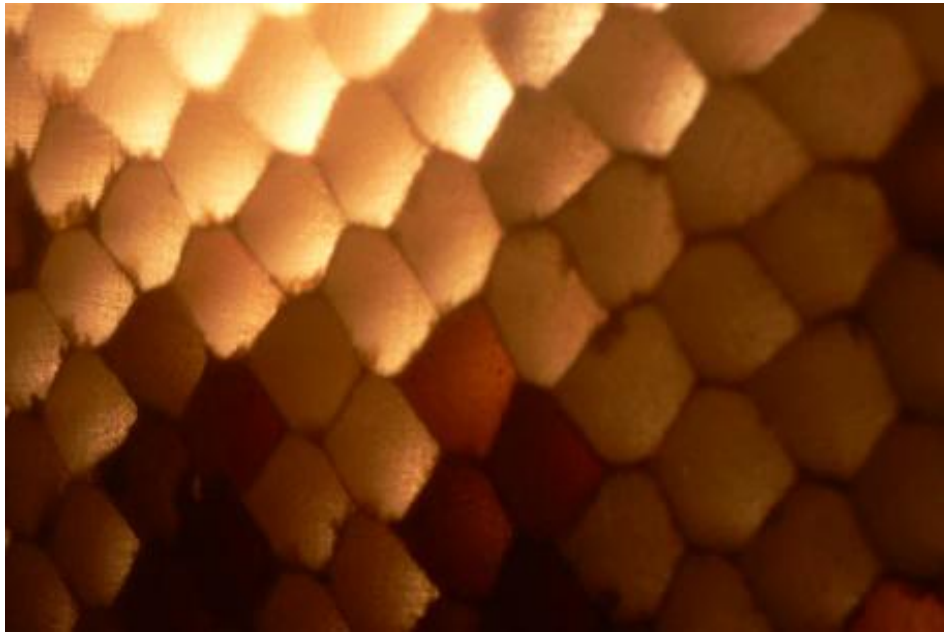


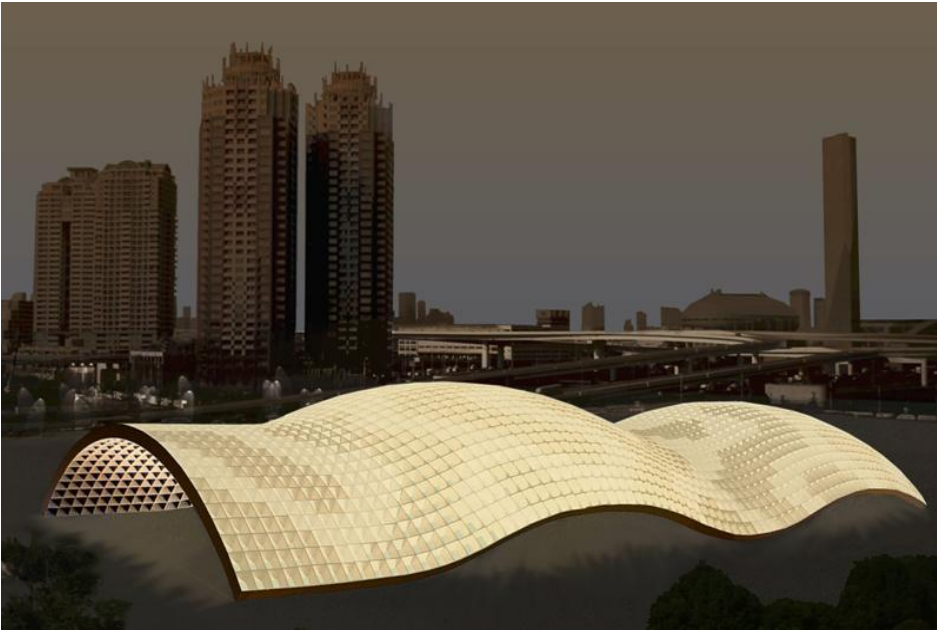
Composite beam sections:



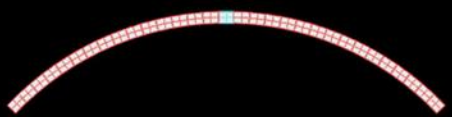
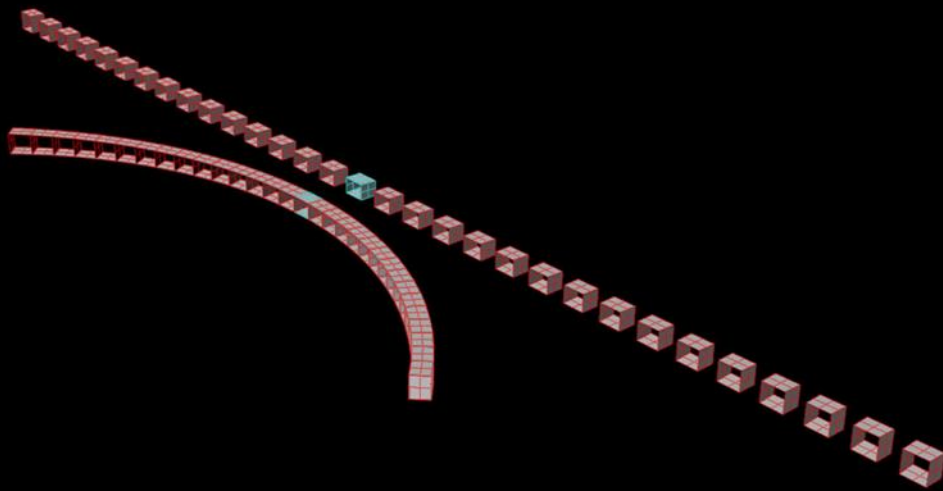
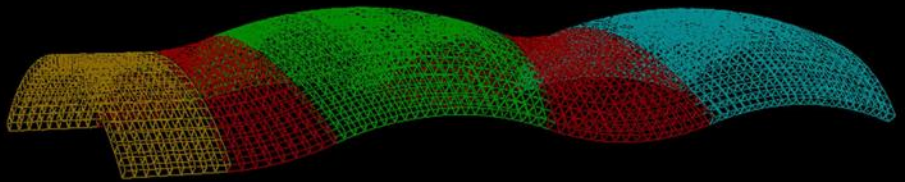
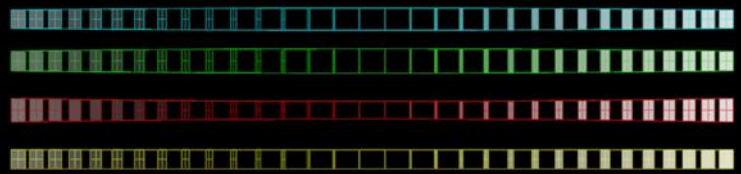
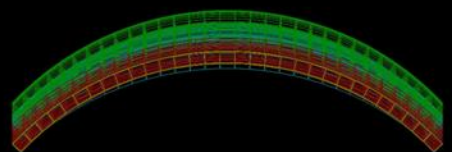
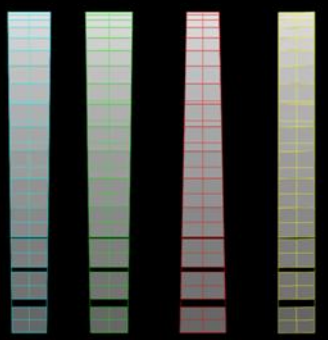
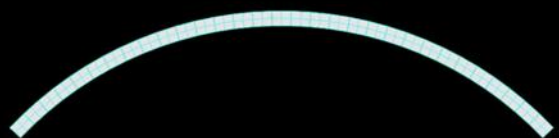
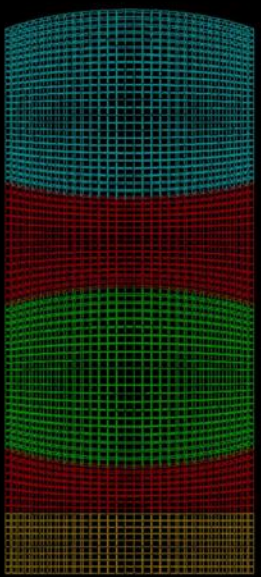
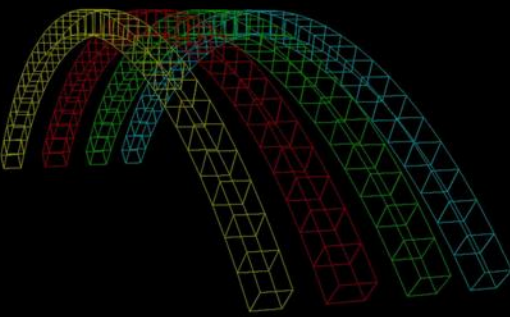
*Prototype of cross-welded
timber panel:*

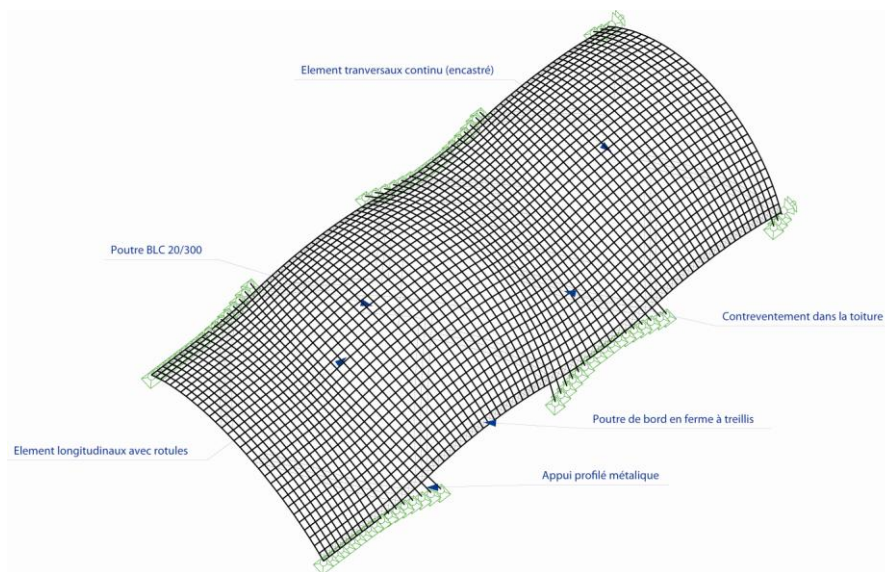
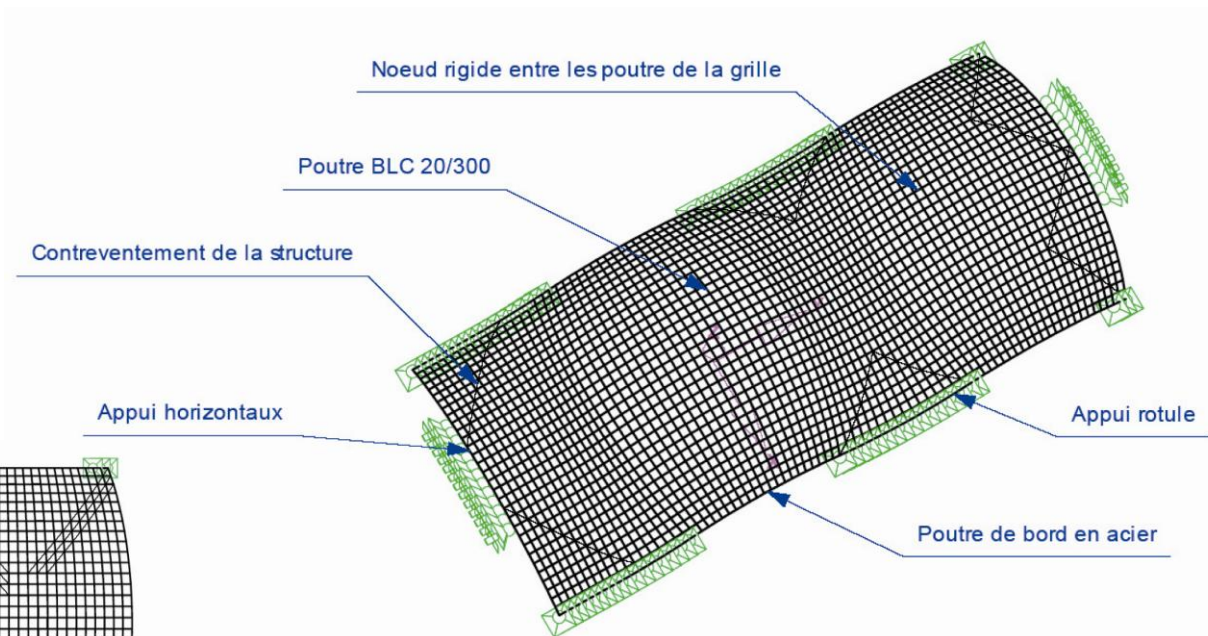
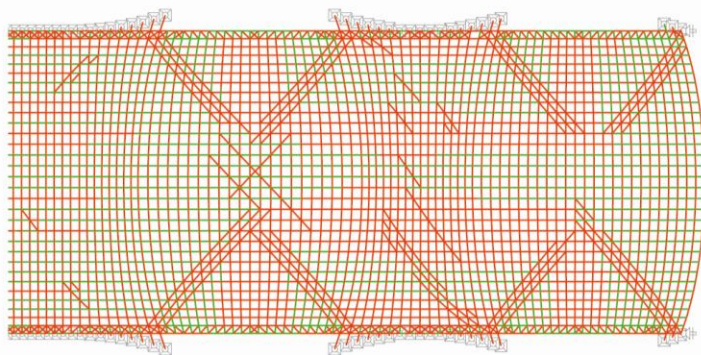
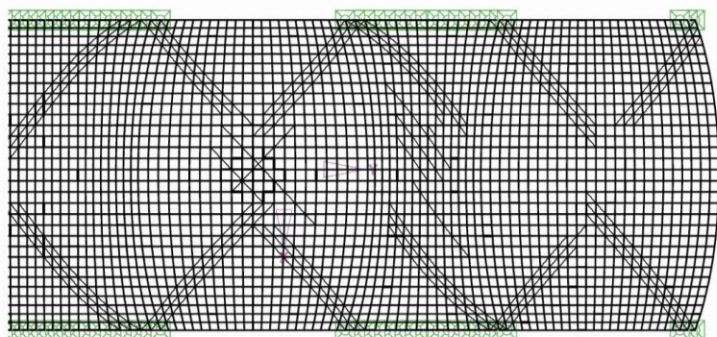


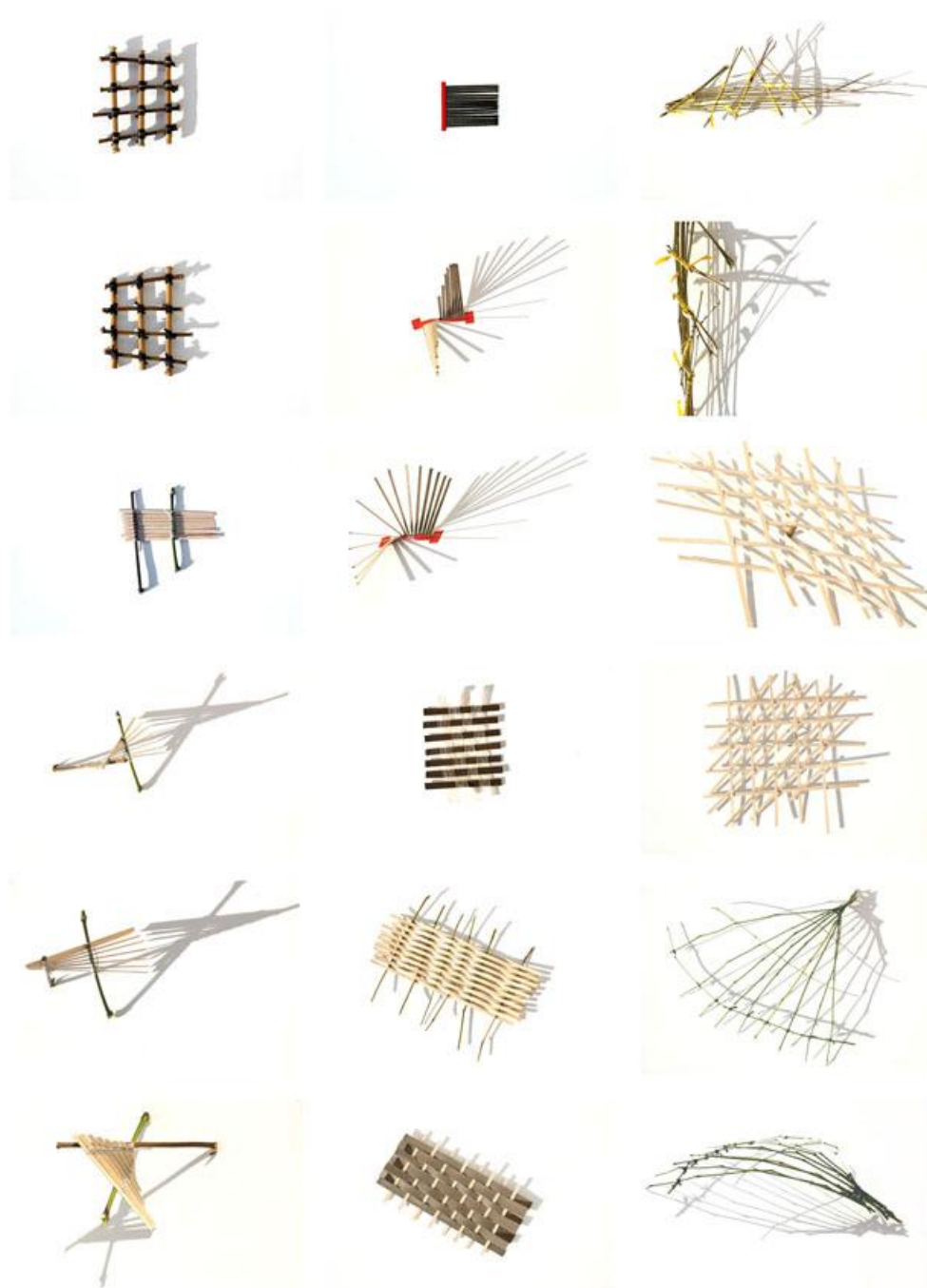






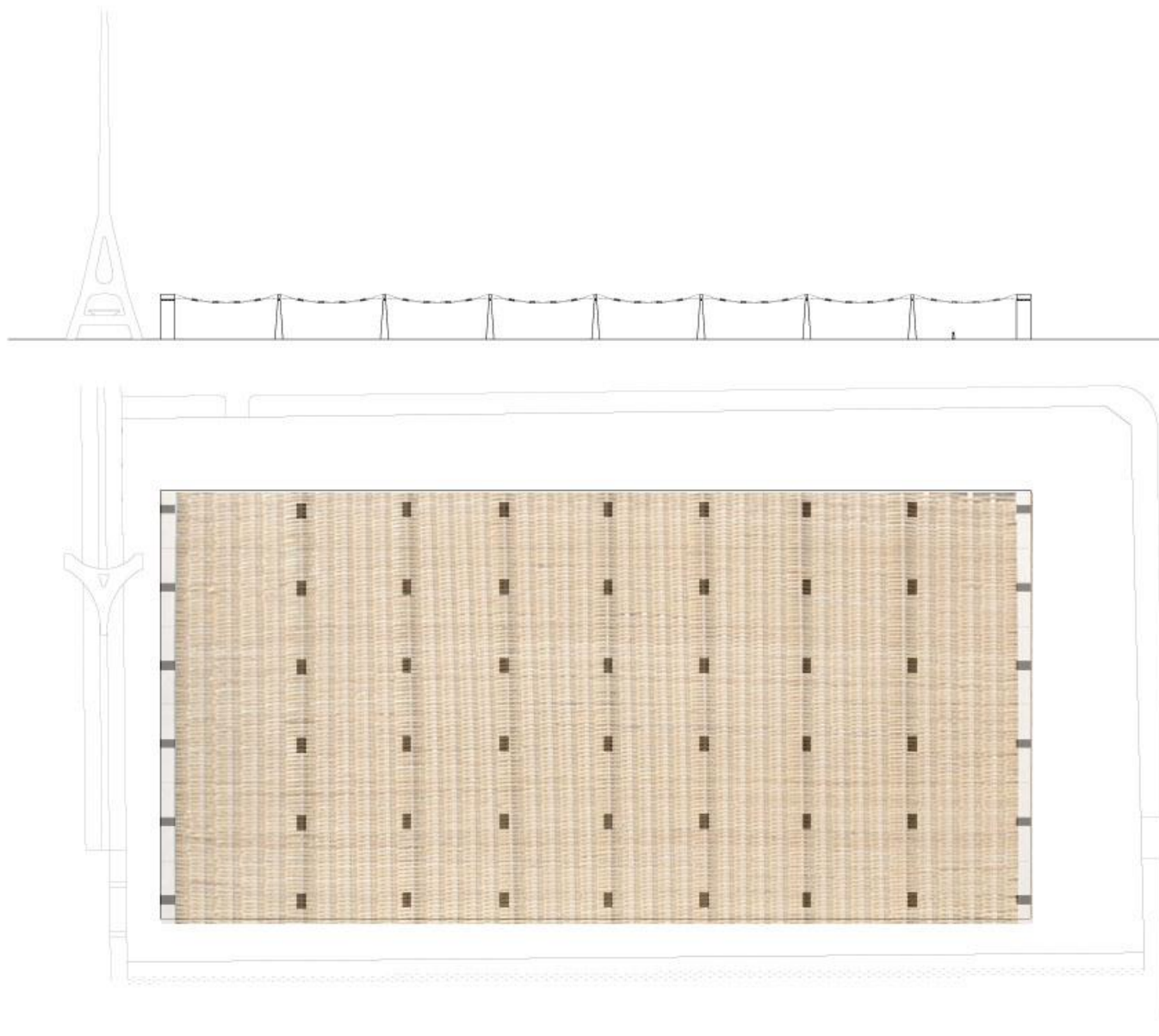




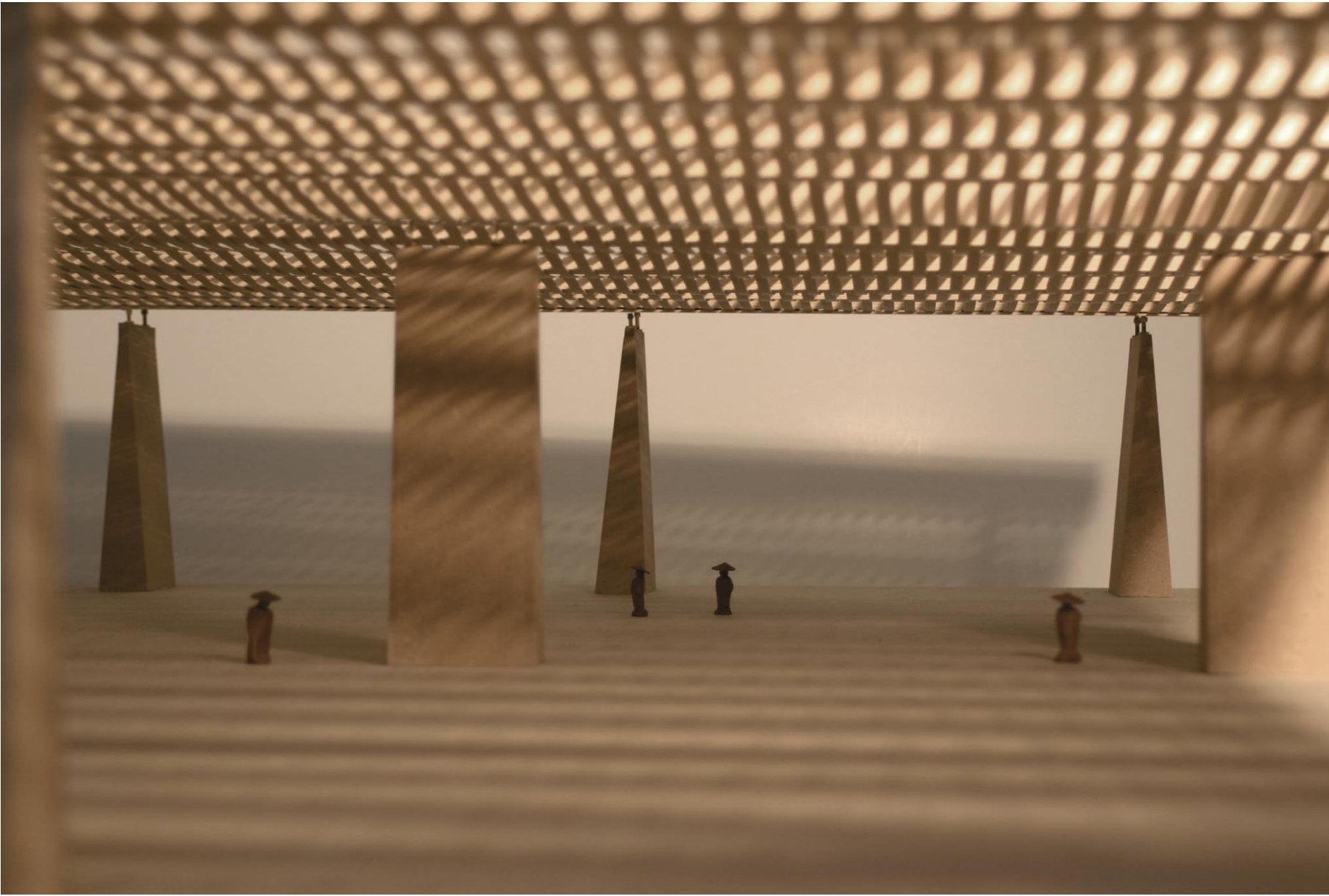


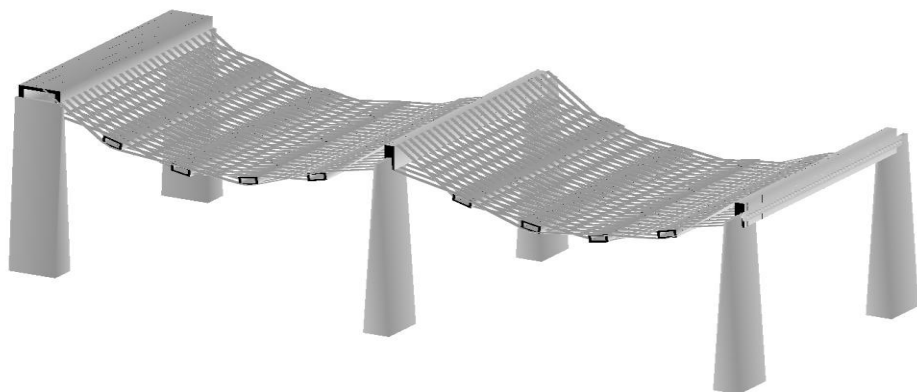
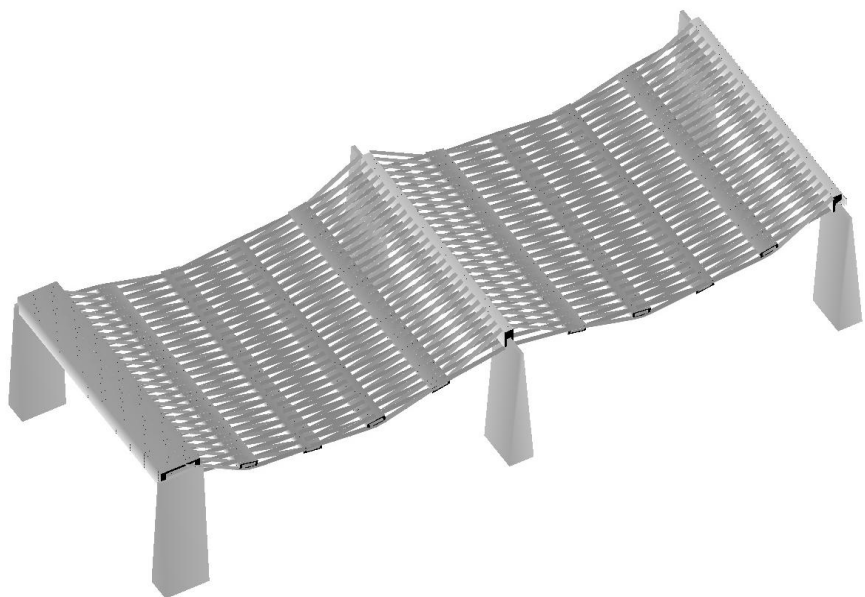
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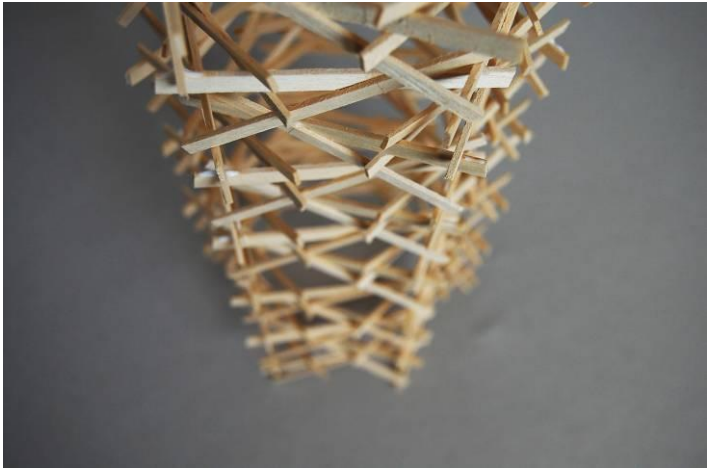
PROJECTION D'OMBRES
ET DE LUMIERES

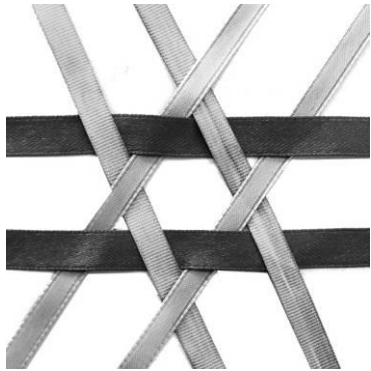


COUPE LONGITUDINALE
PLAN PILIERS ET NATTE

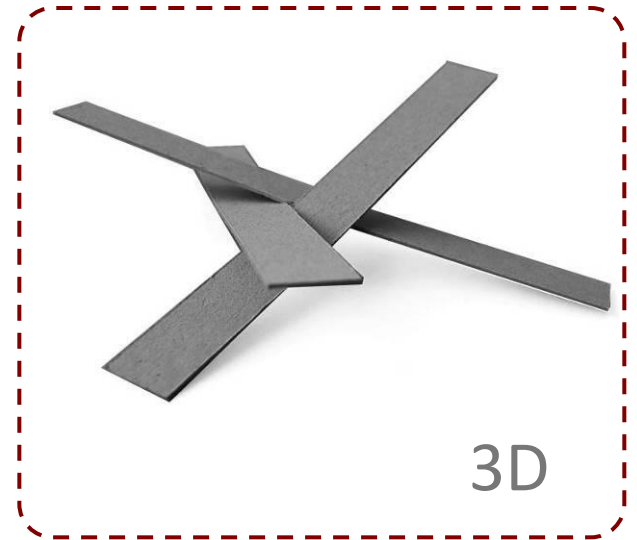




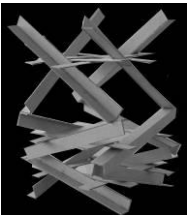
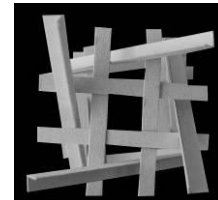
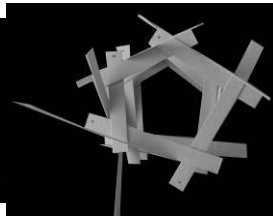
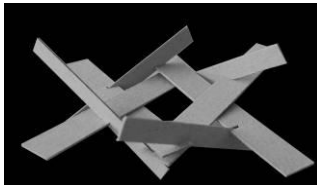
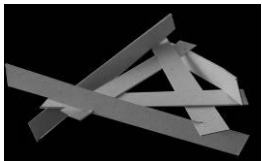




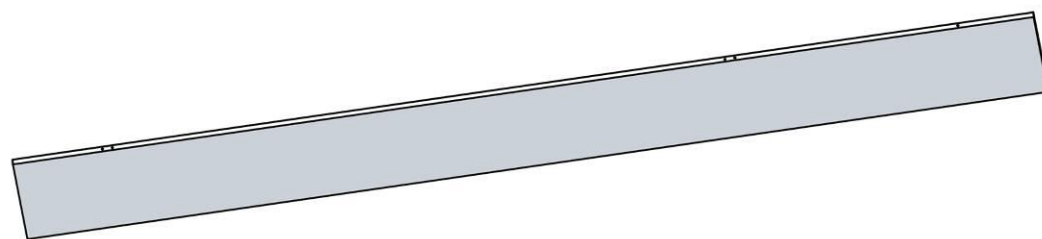
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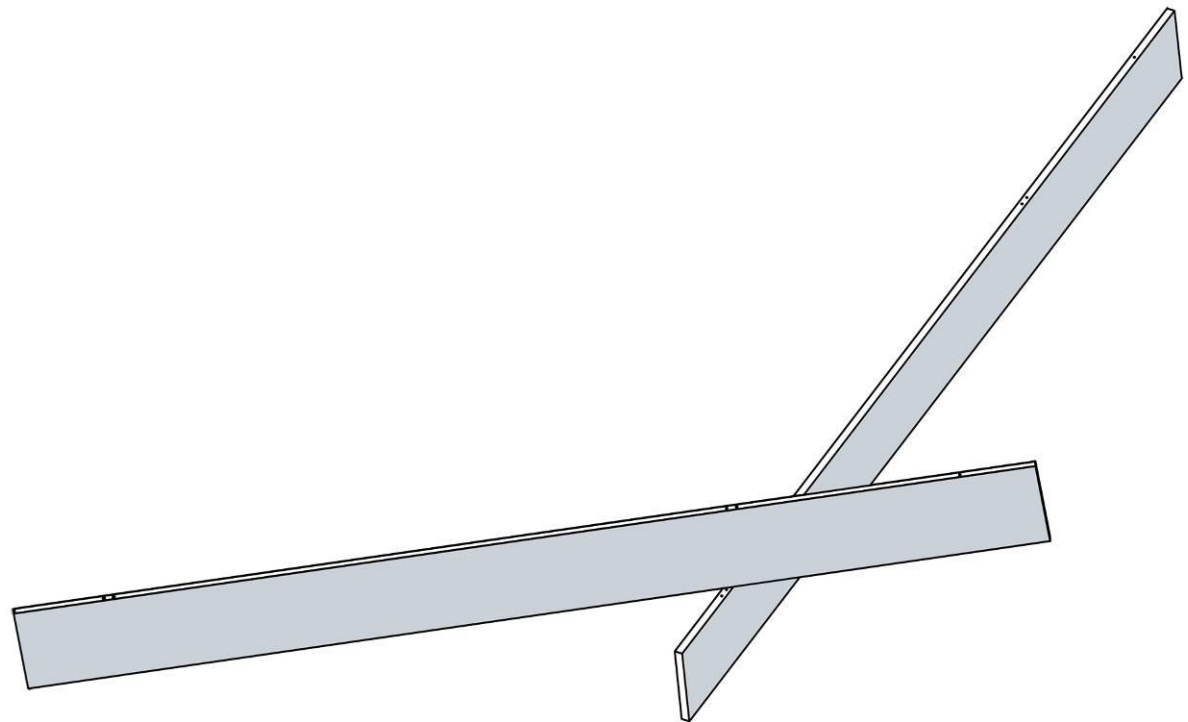
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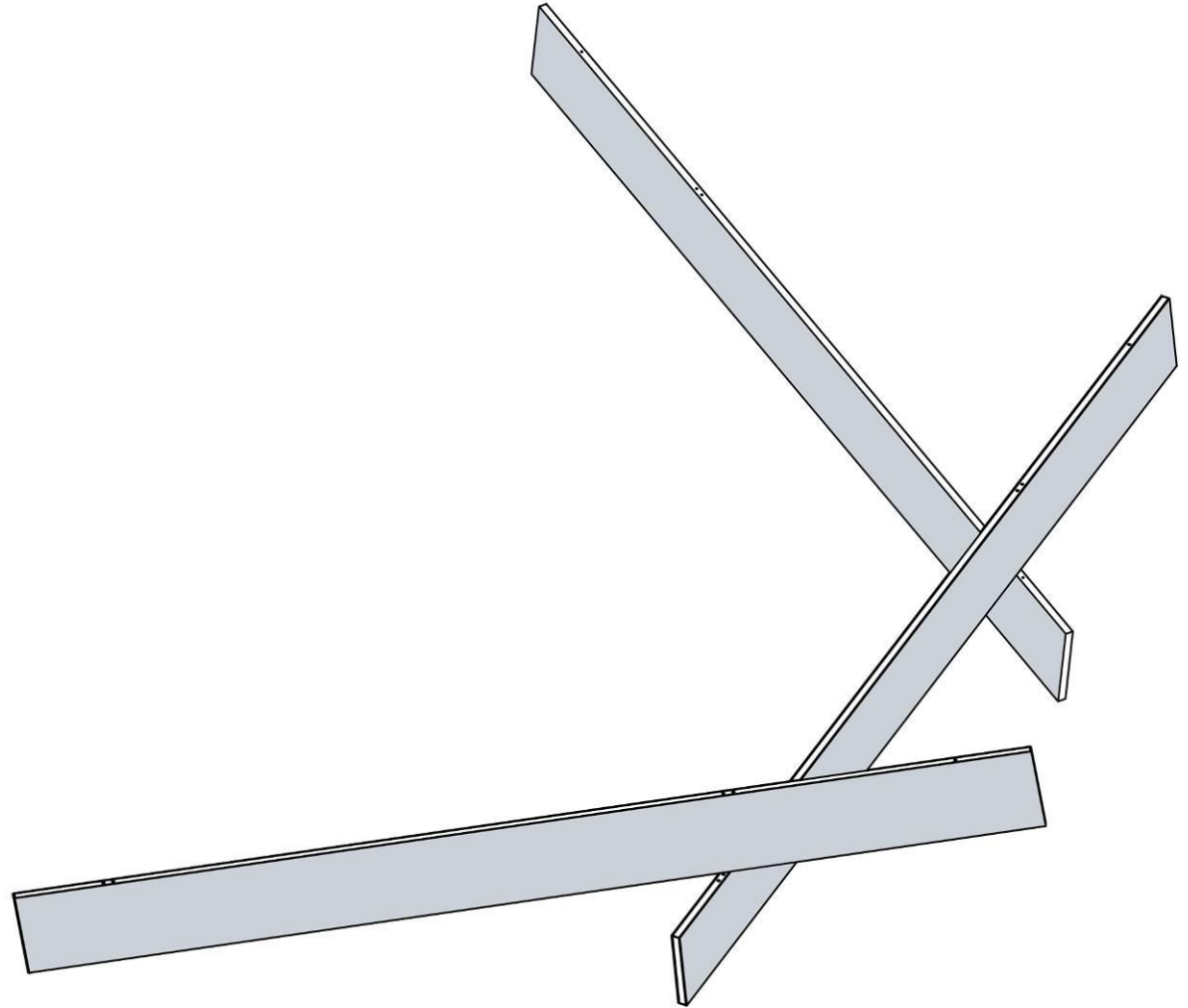




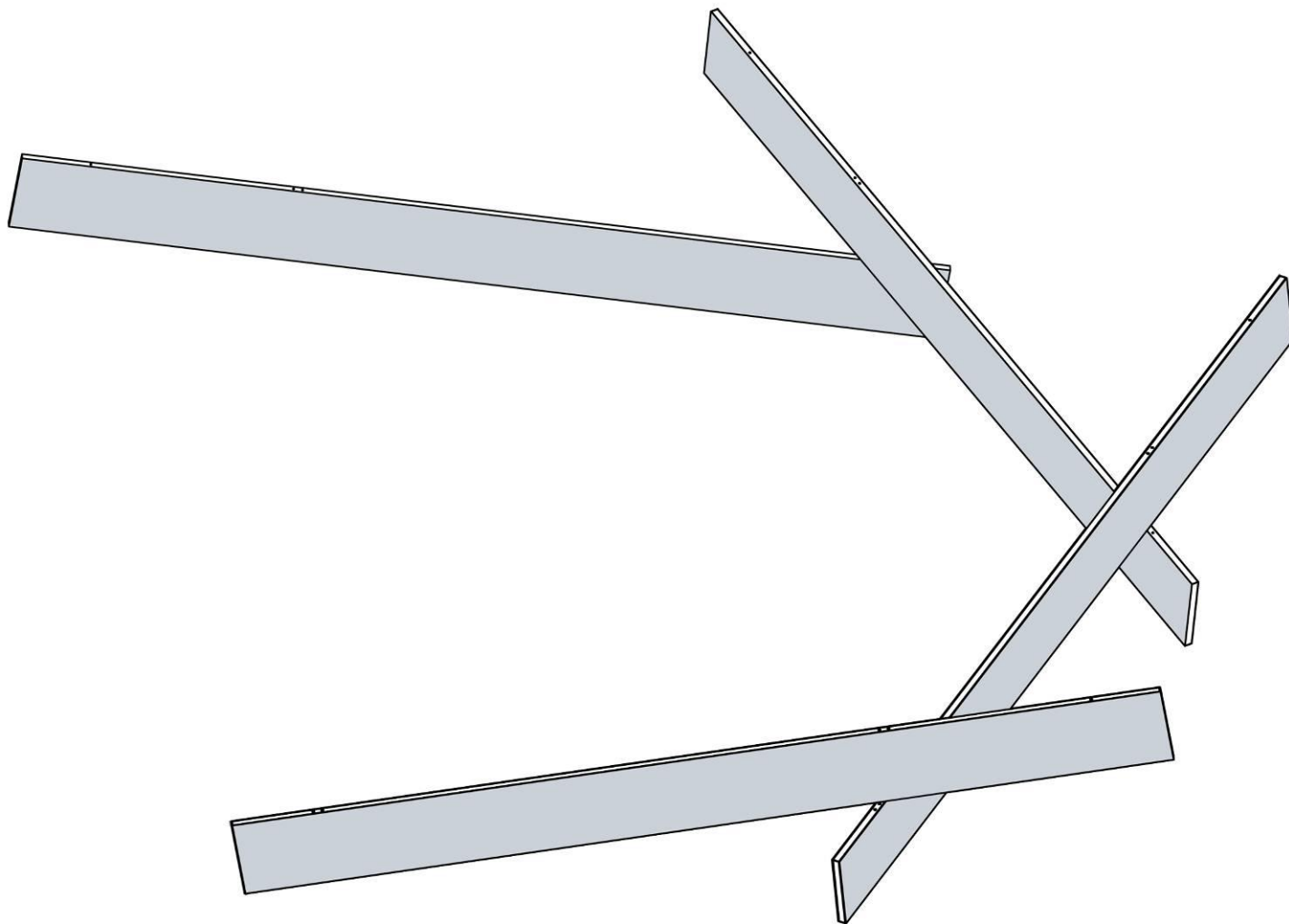
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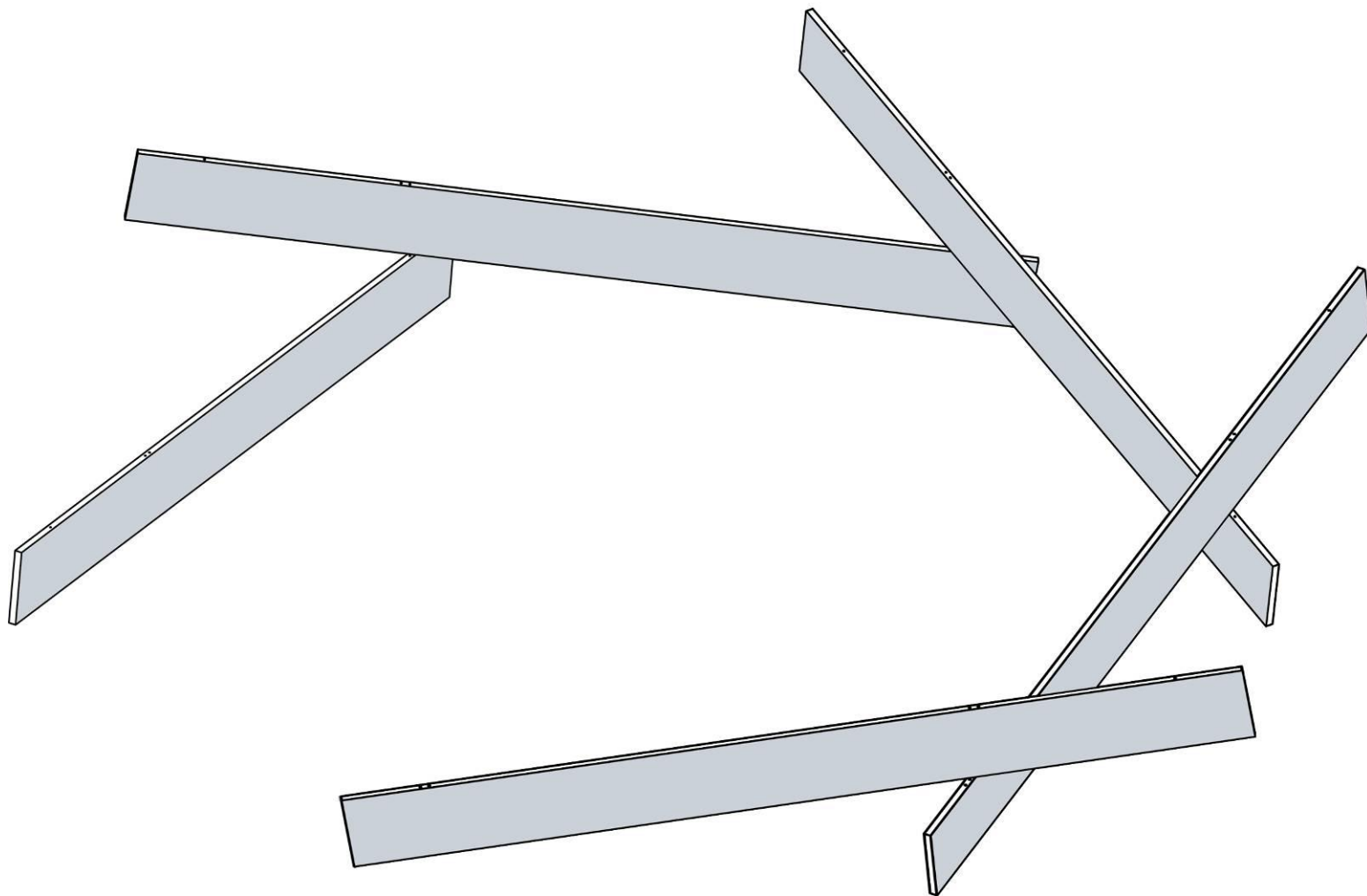
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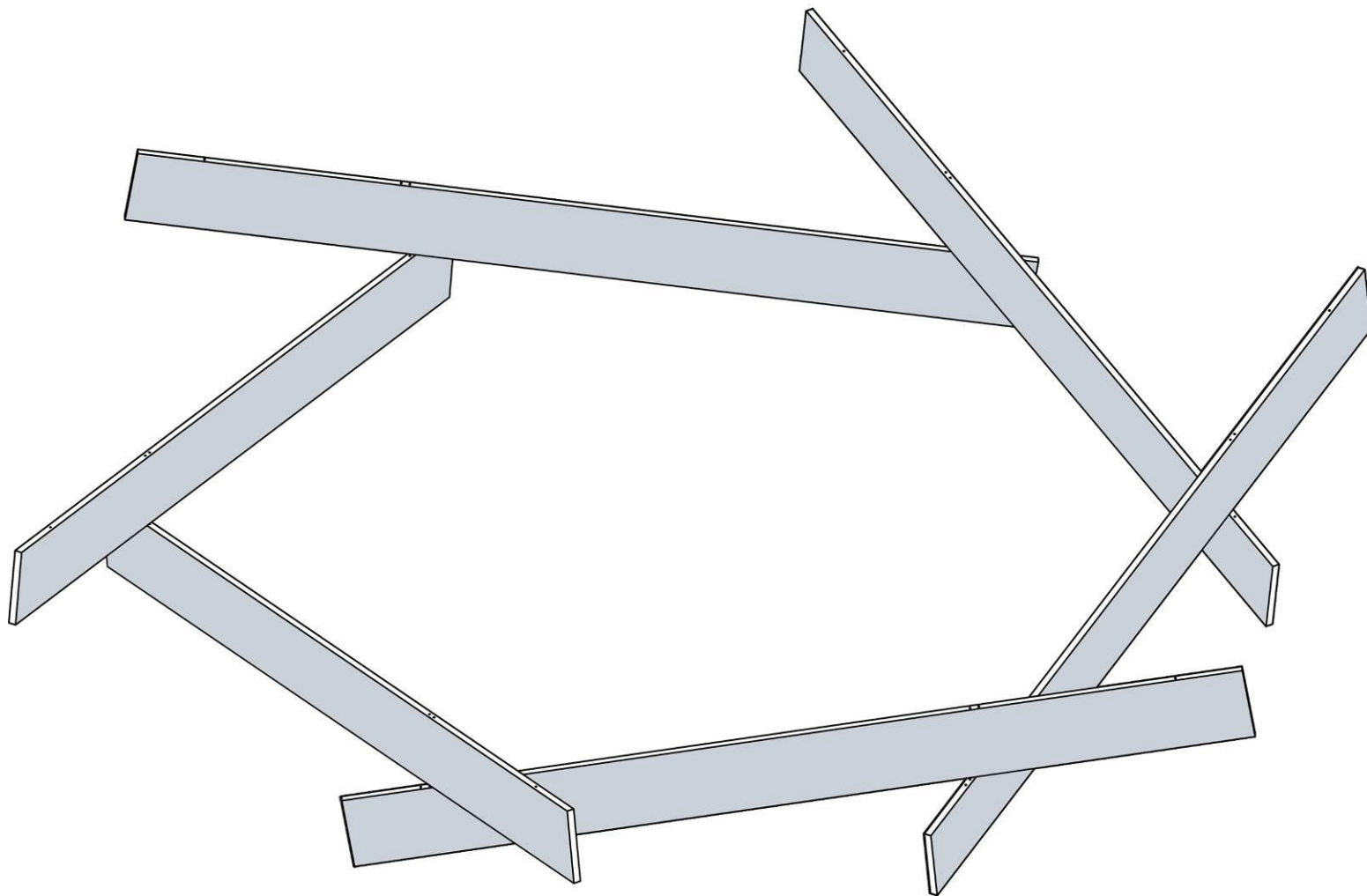
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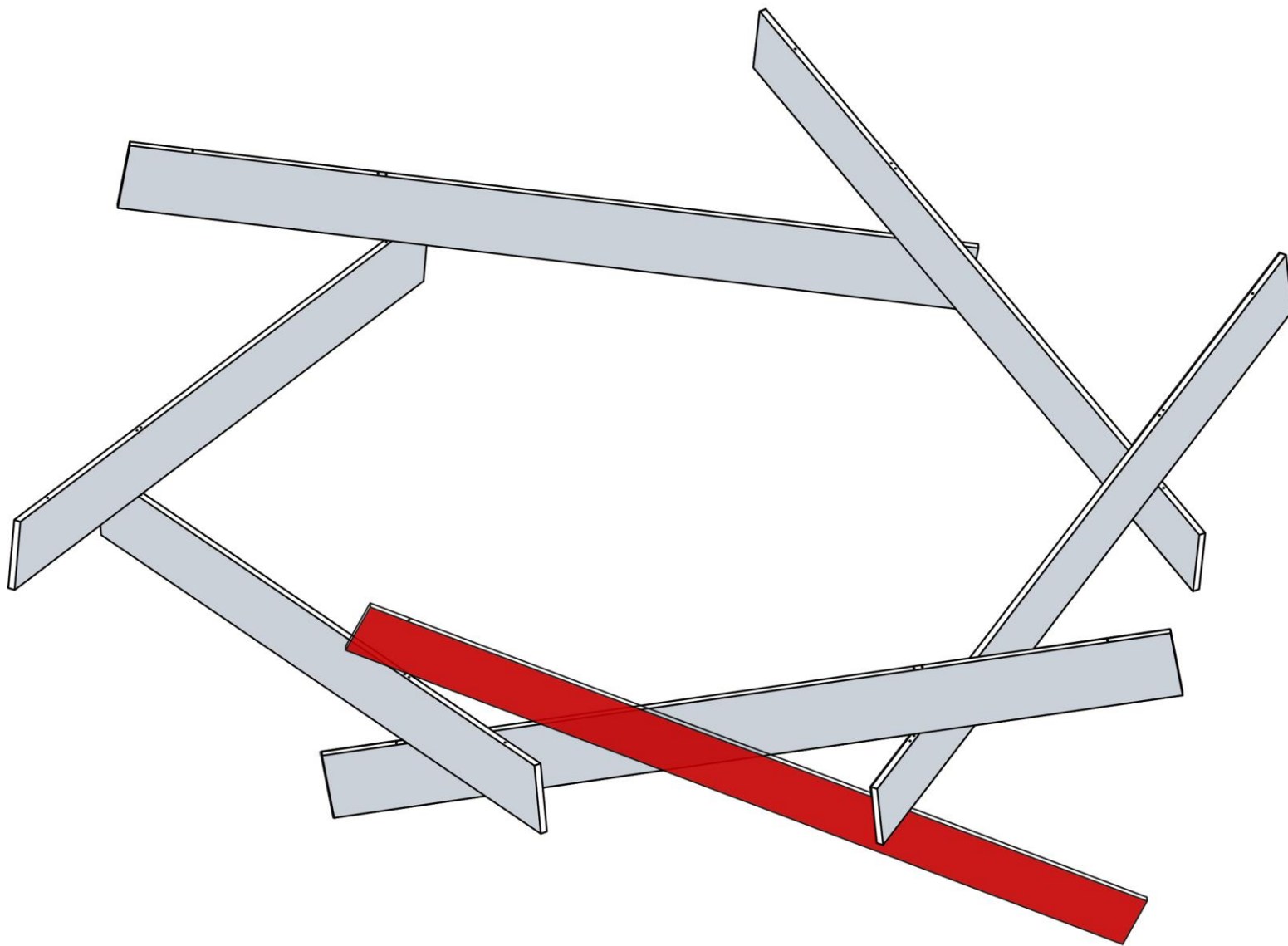
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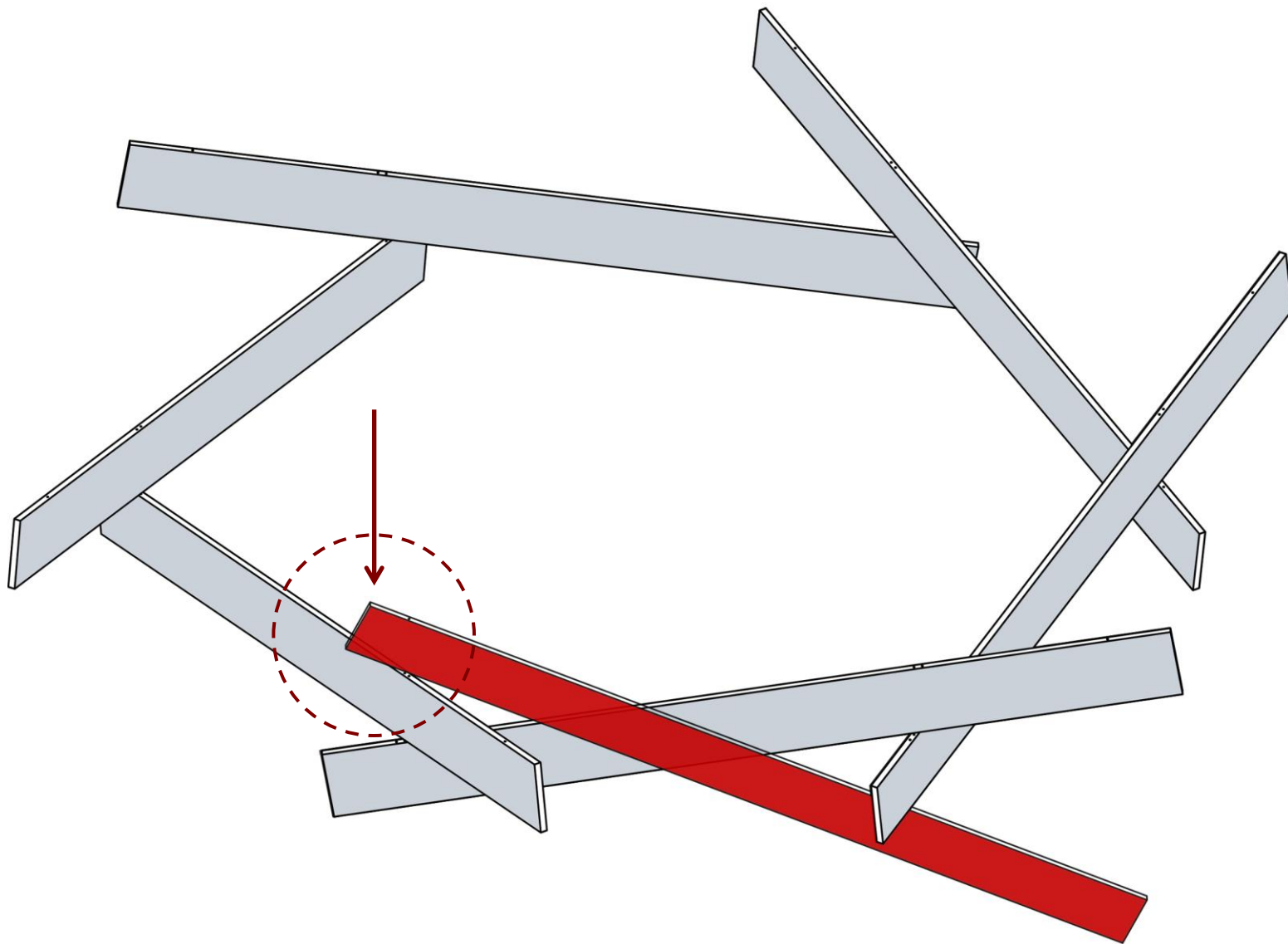
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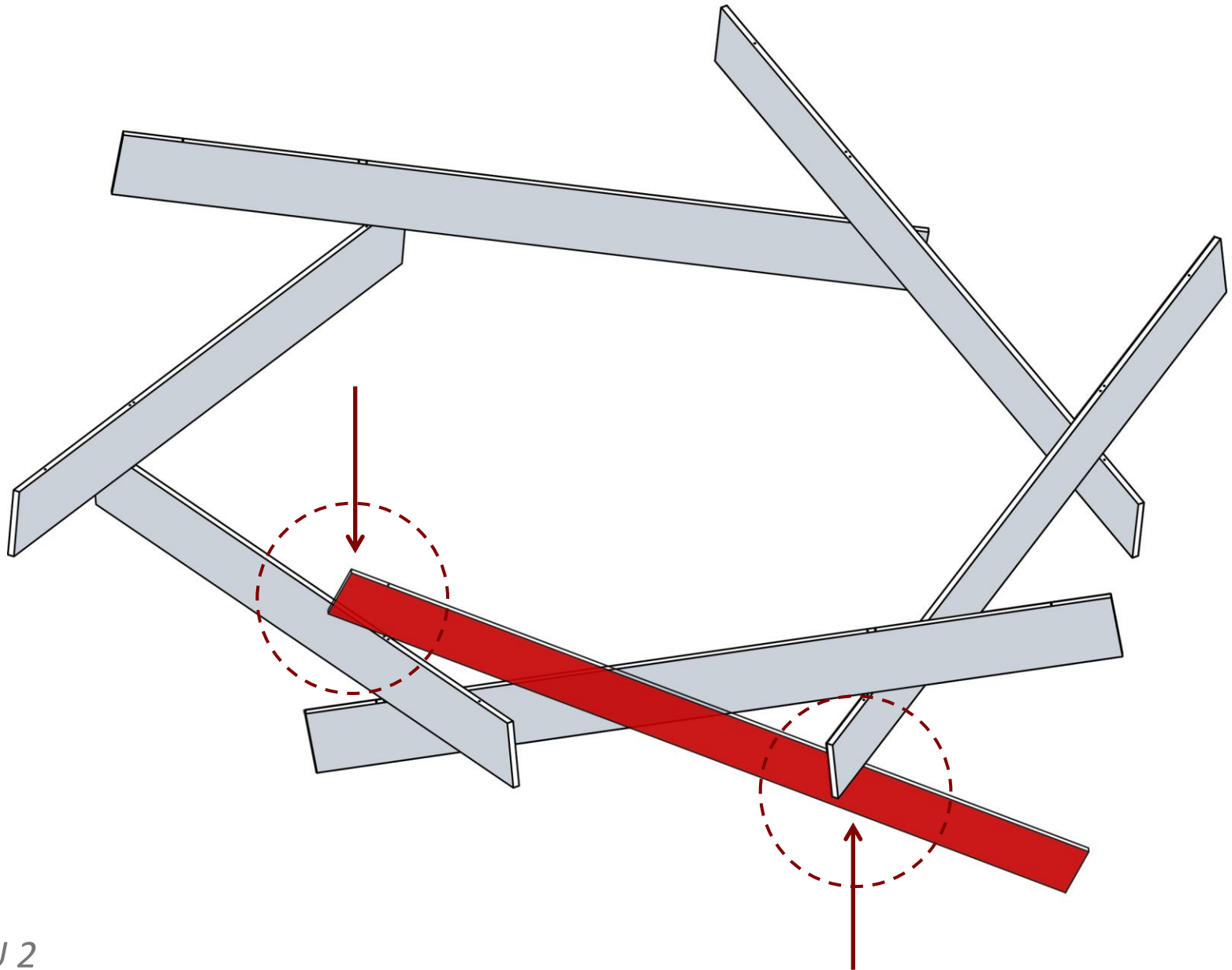
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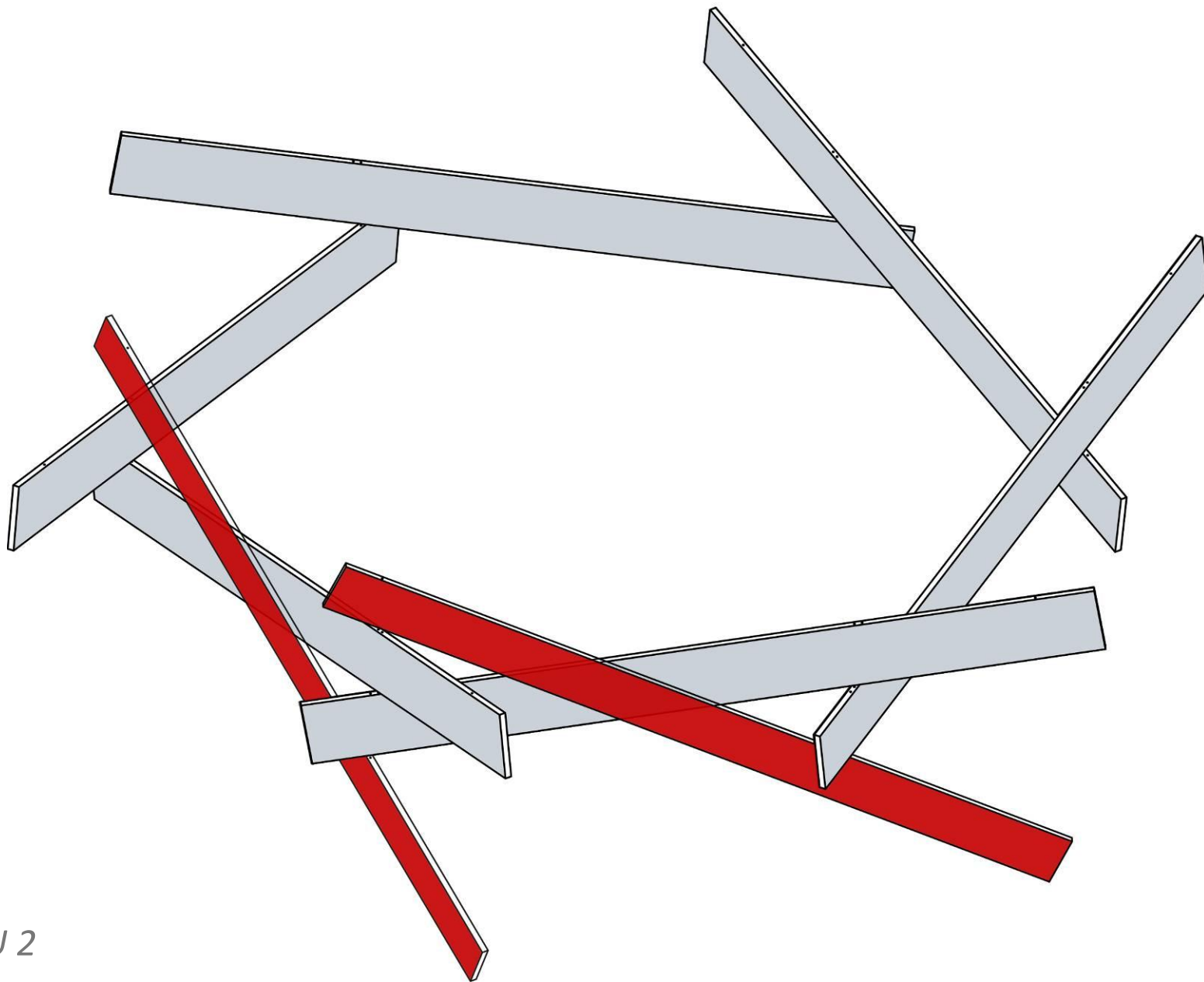
TISSU 2



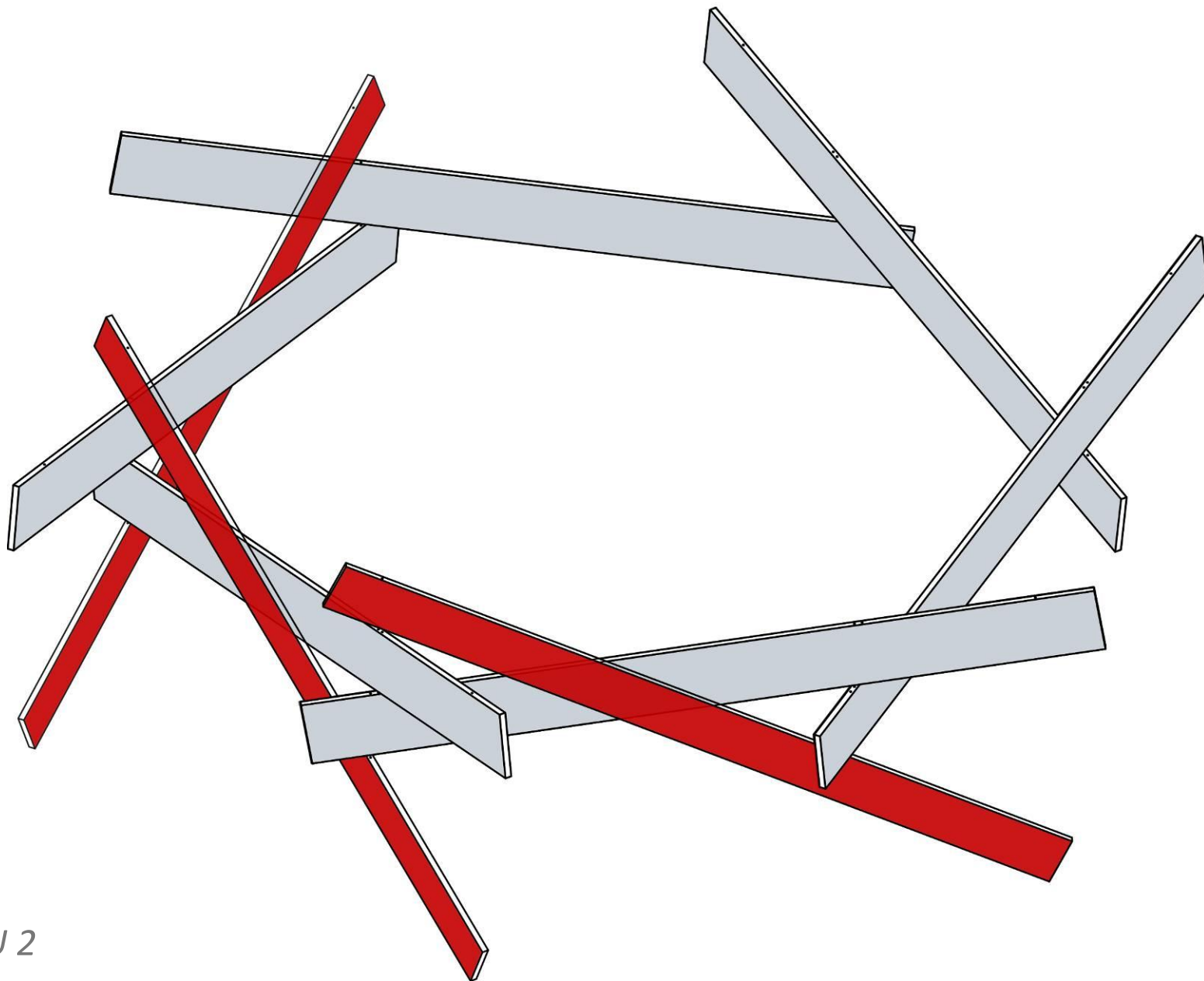
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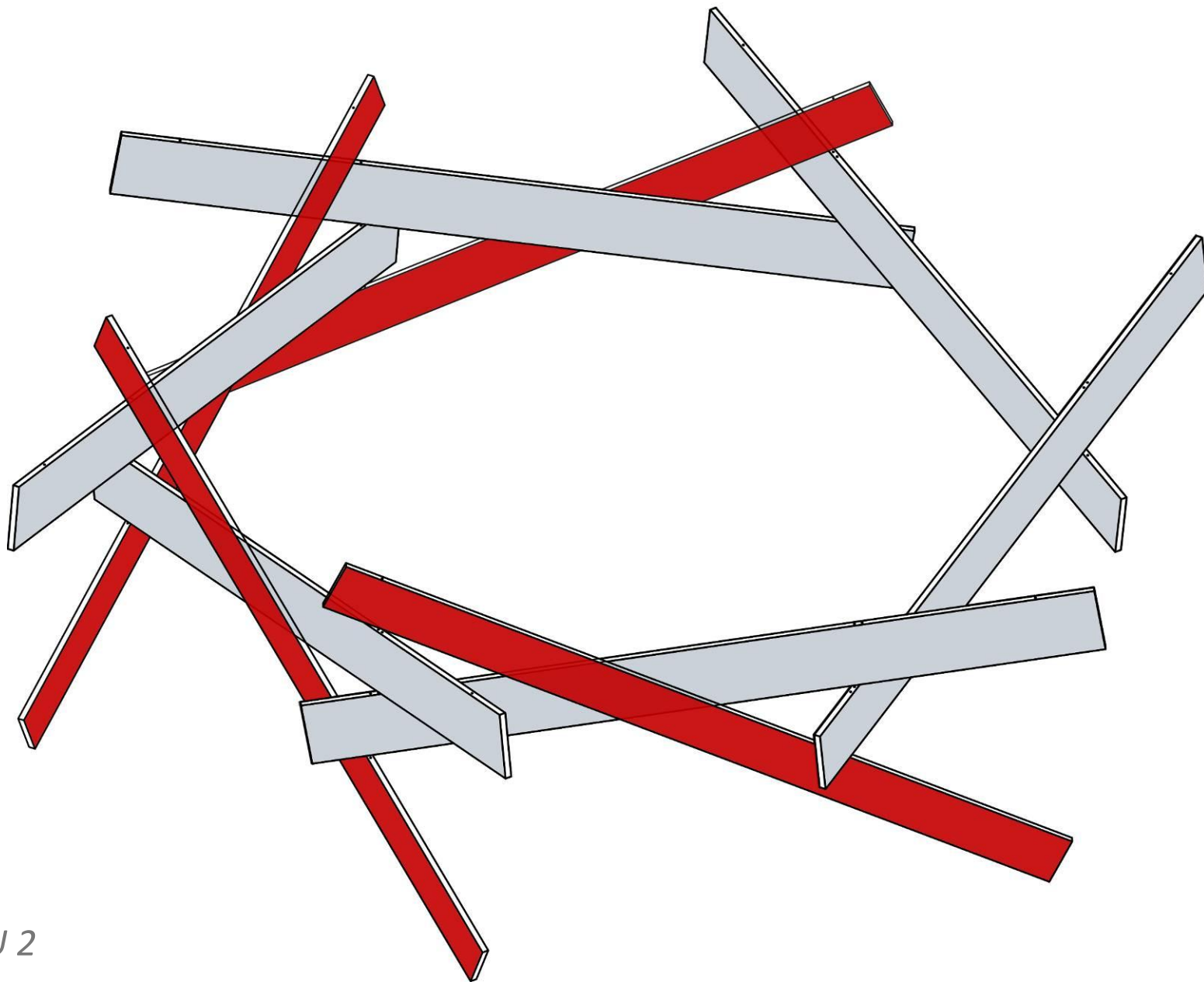
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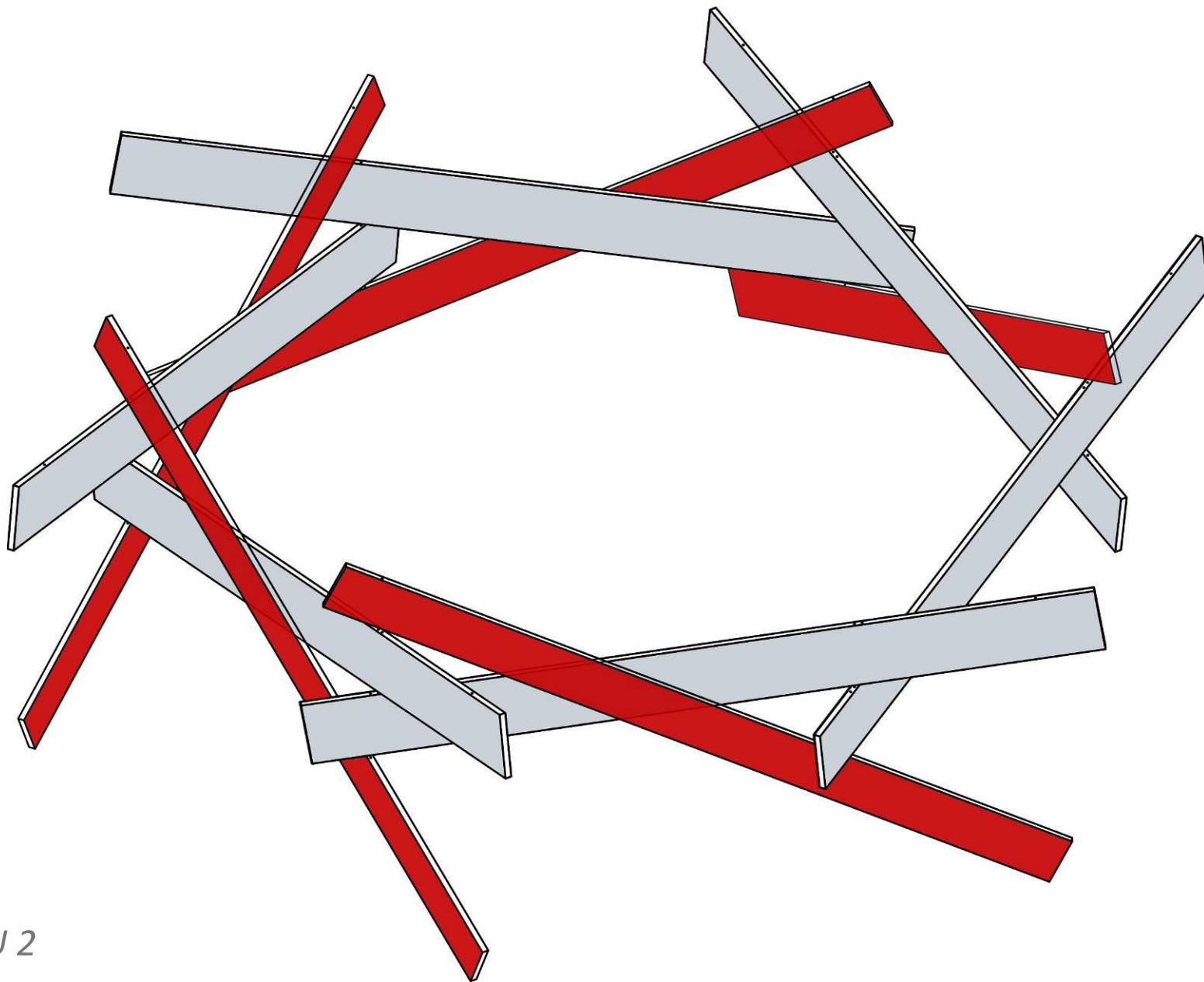
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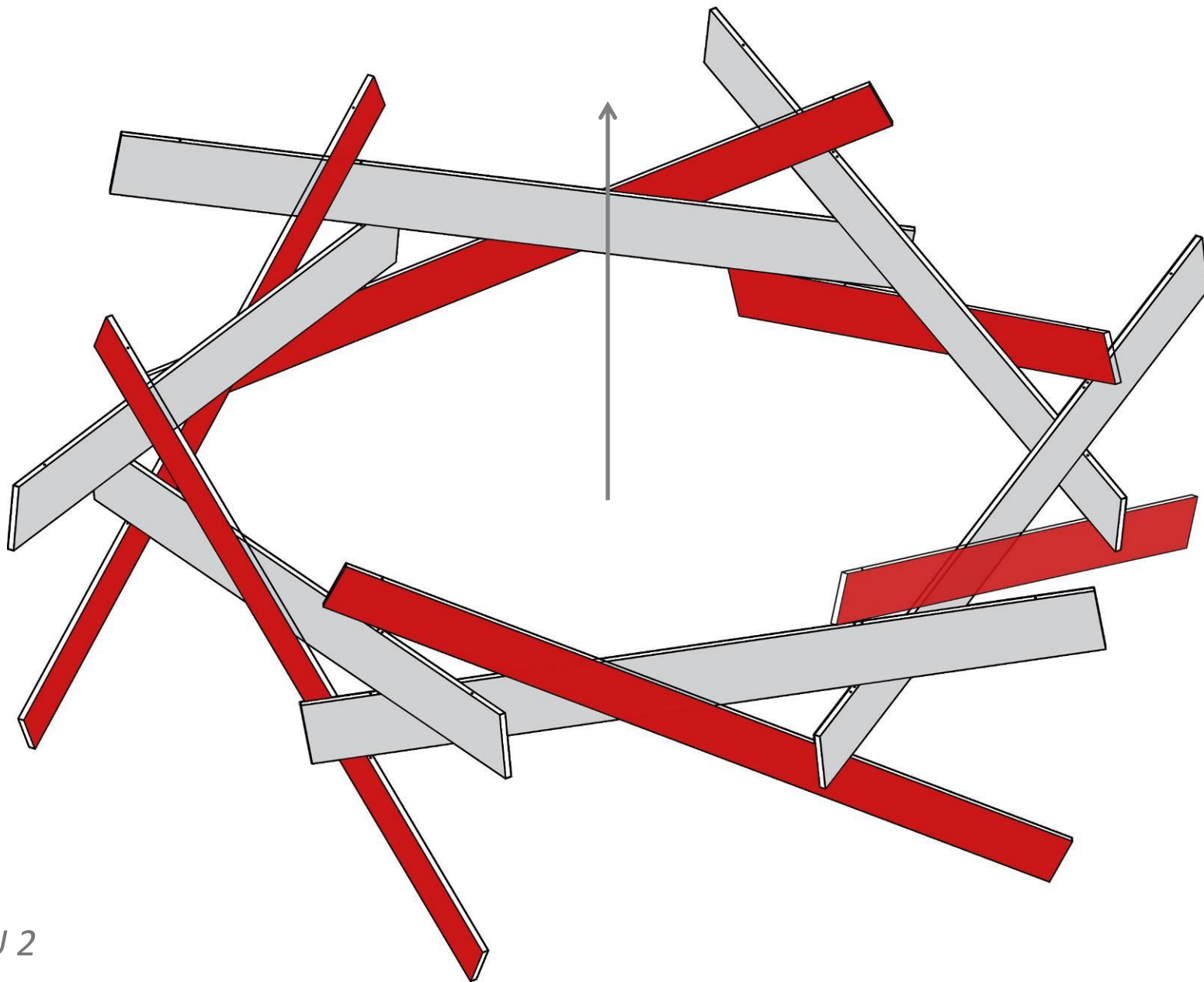
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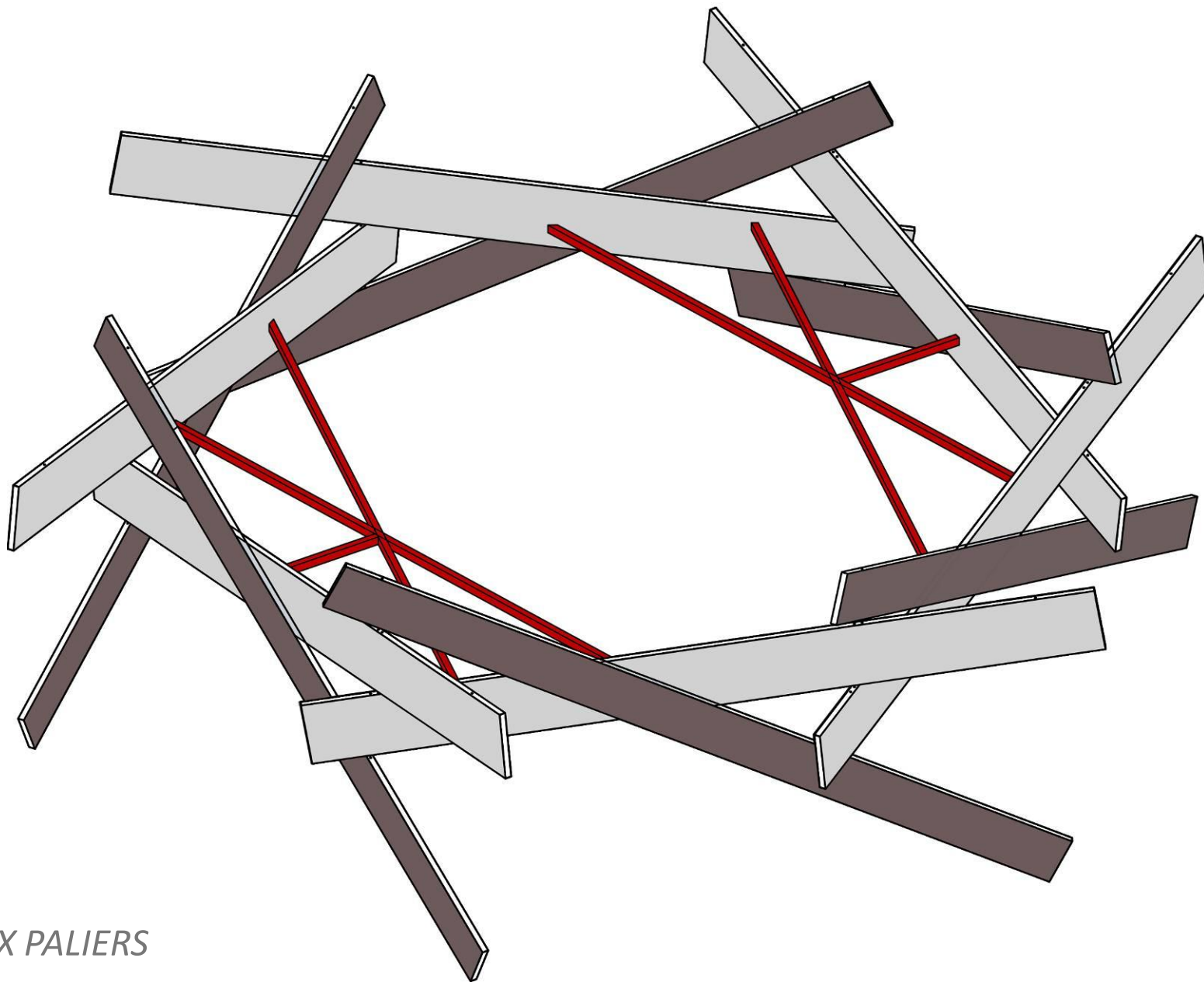
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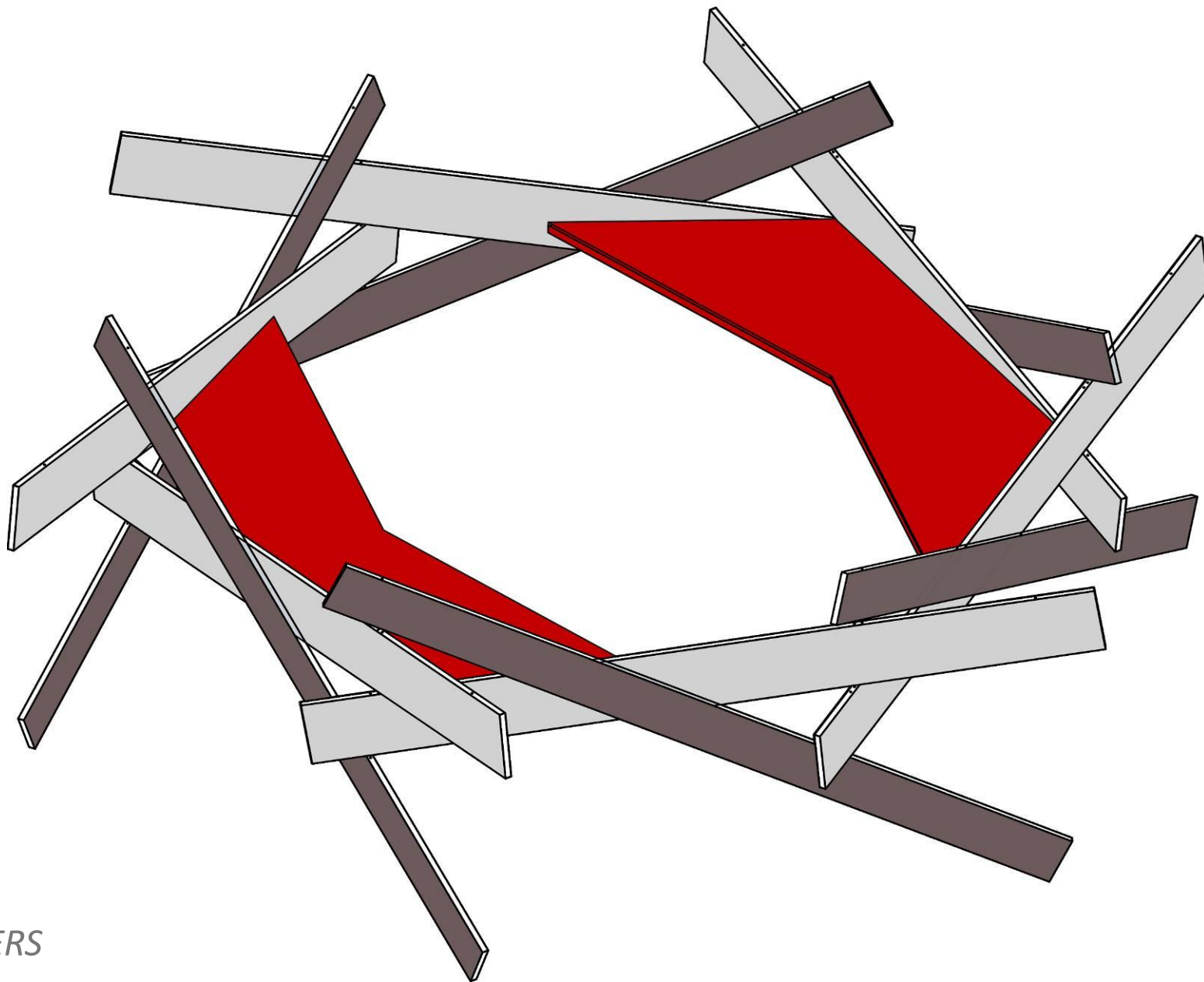
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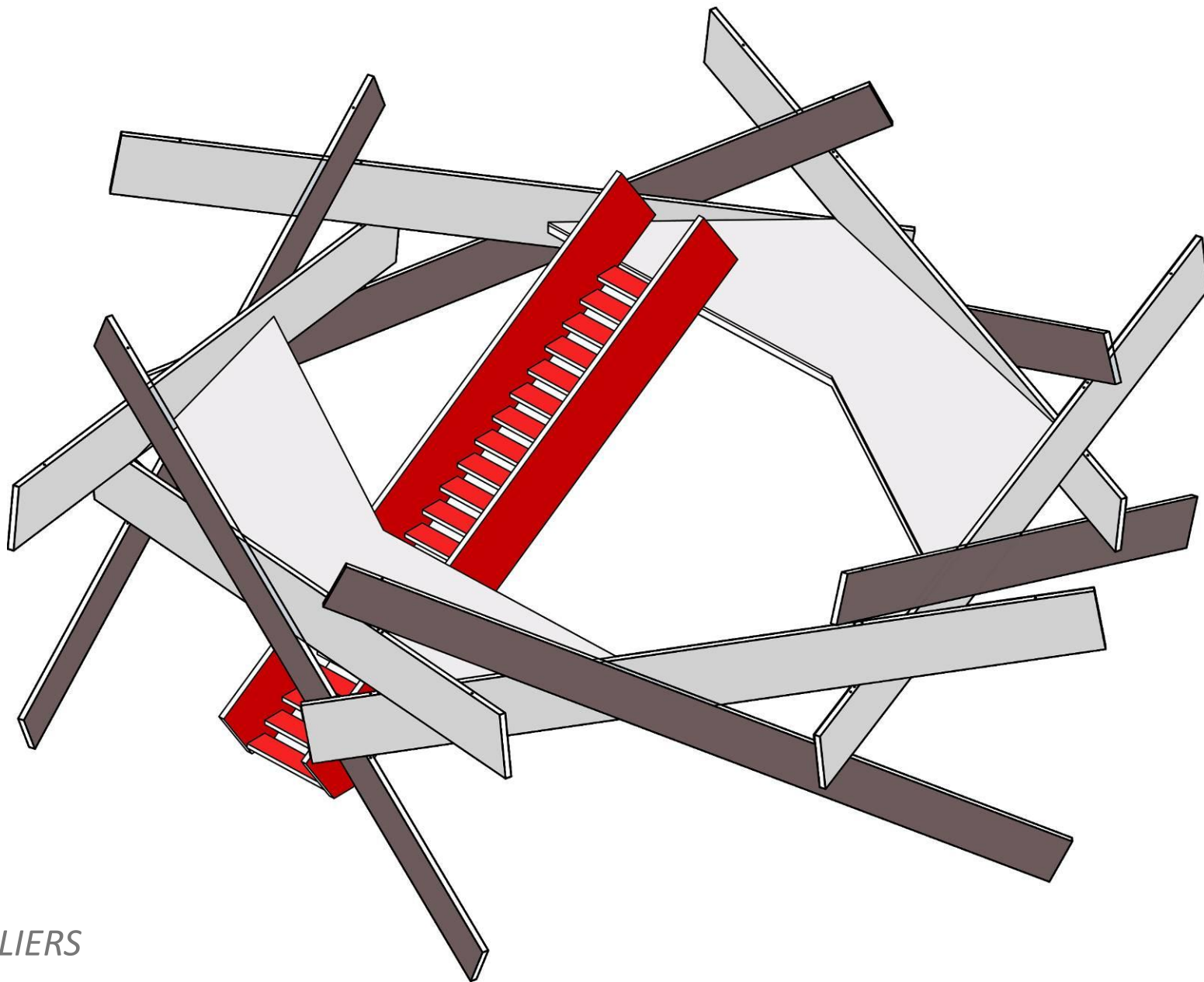
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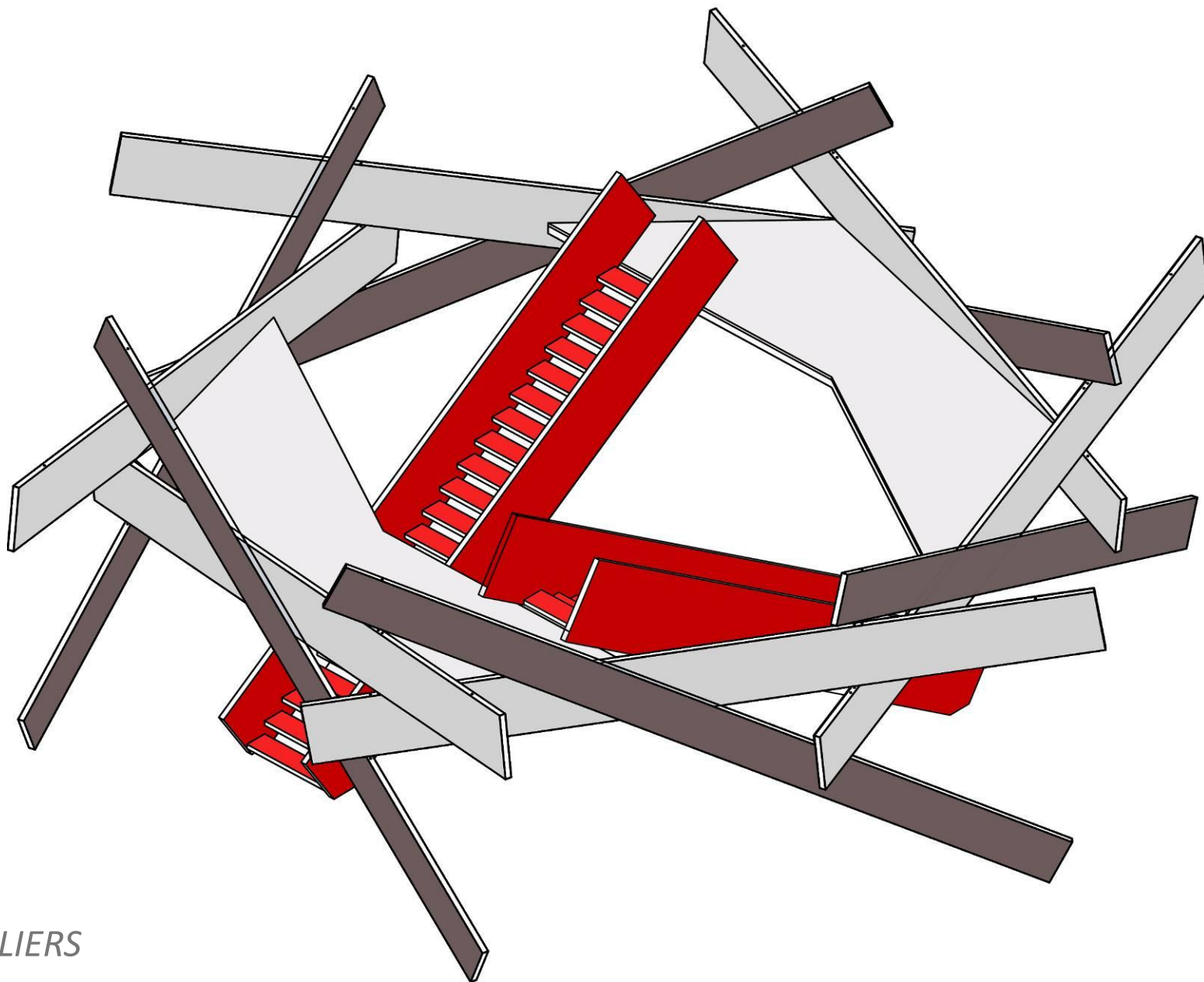
CROIX PALIERS



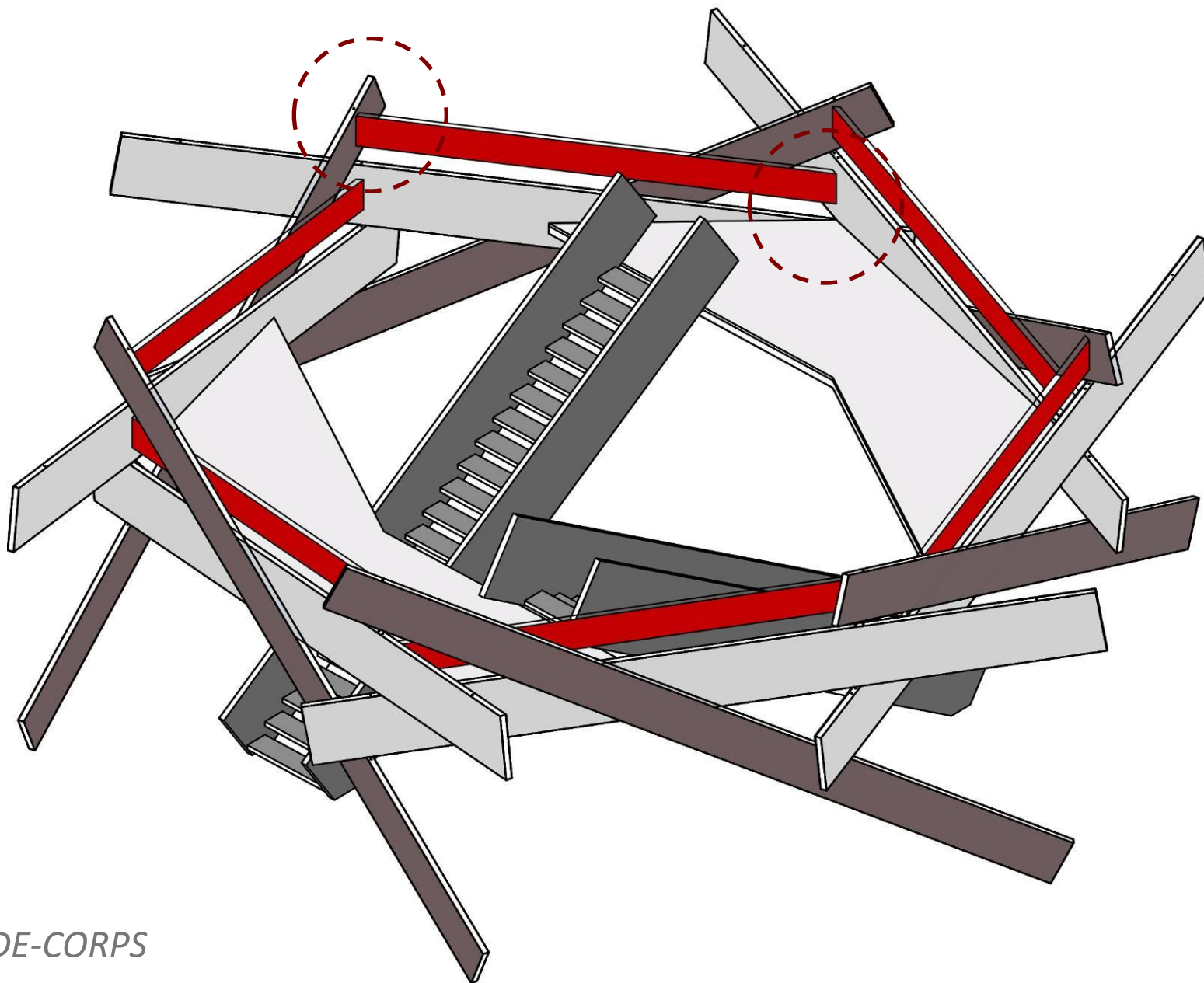
PALIER



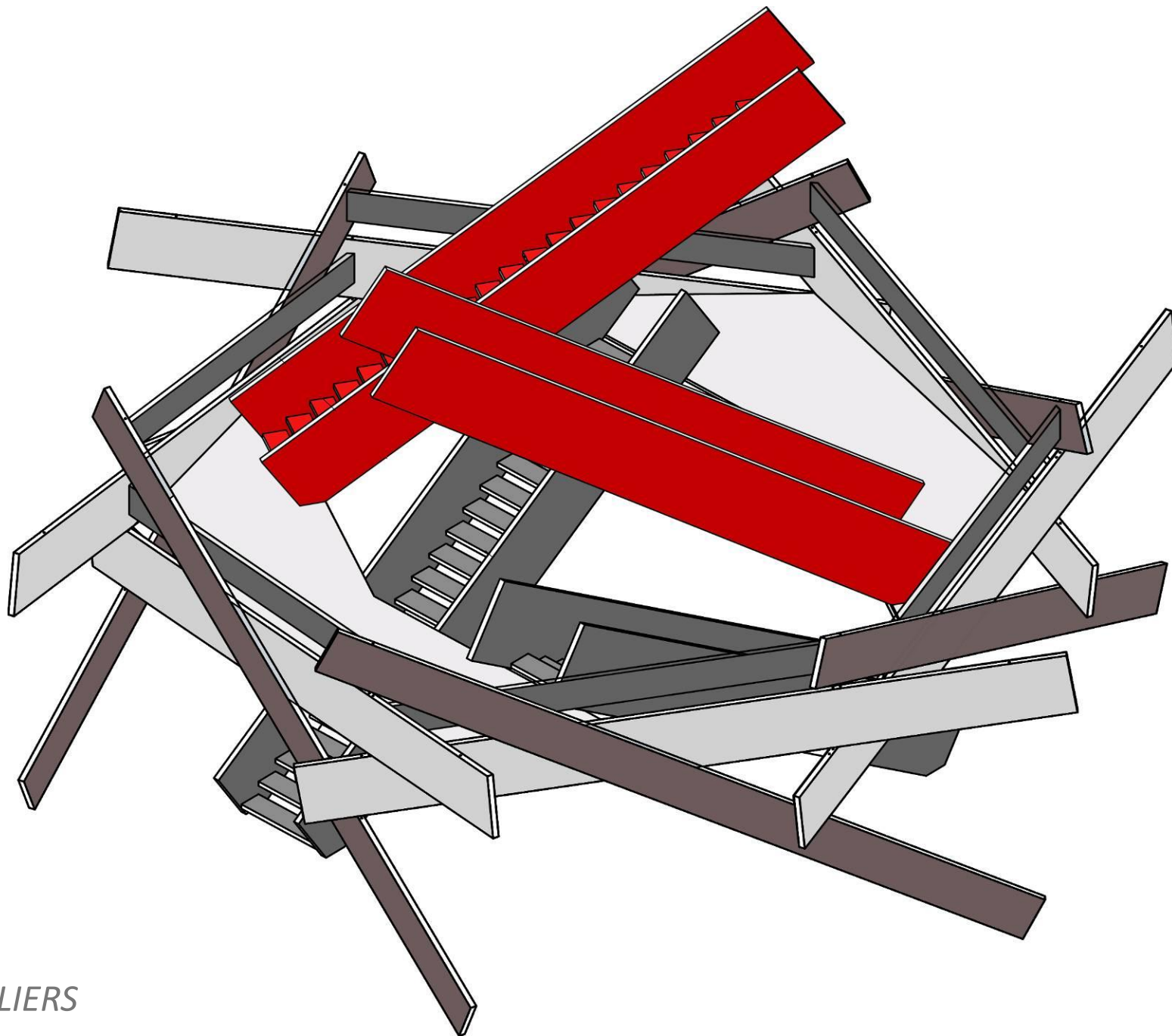
ESCALIERS



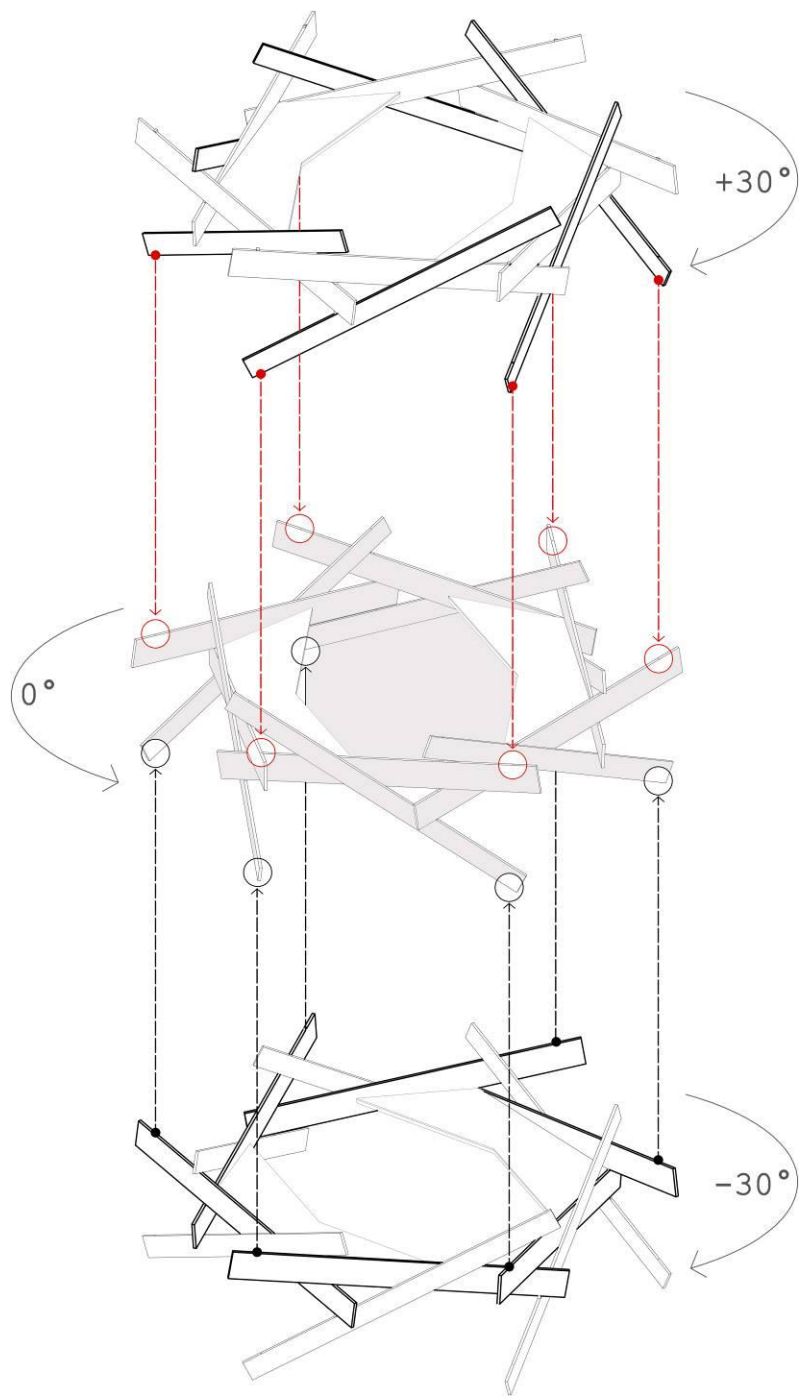
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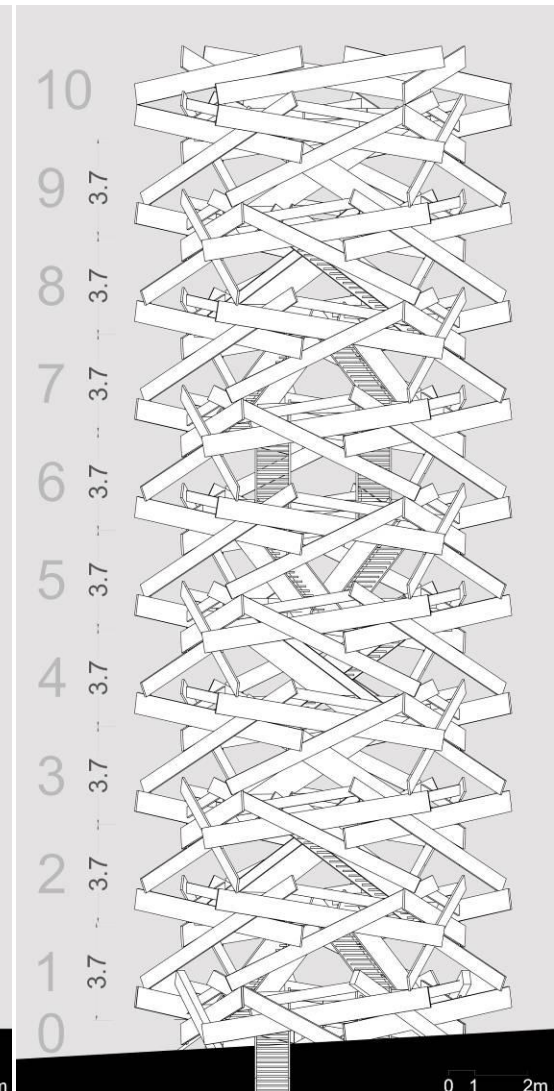
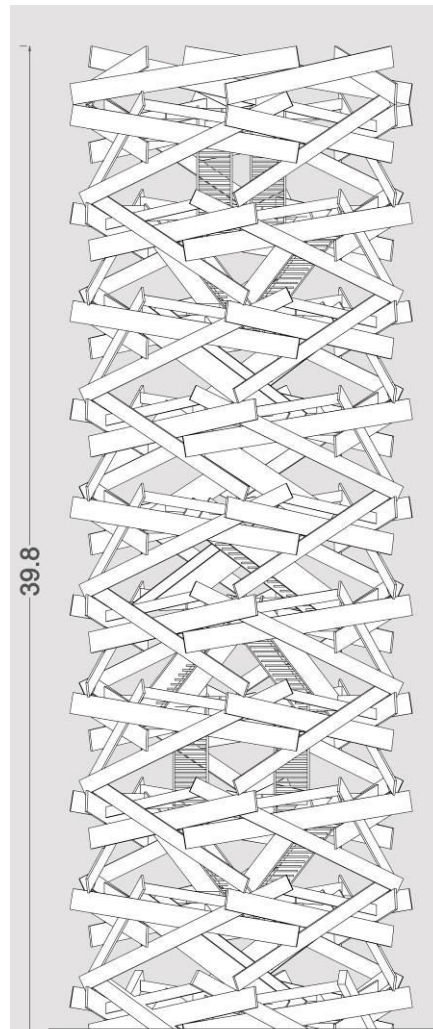
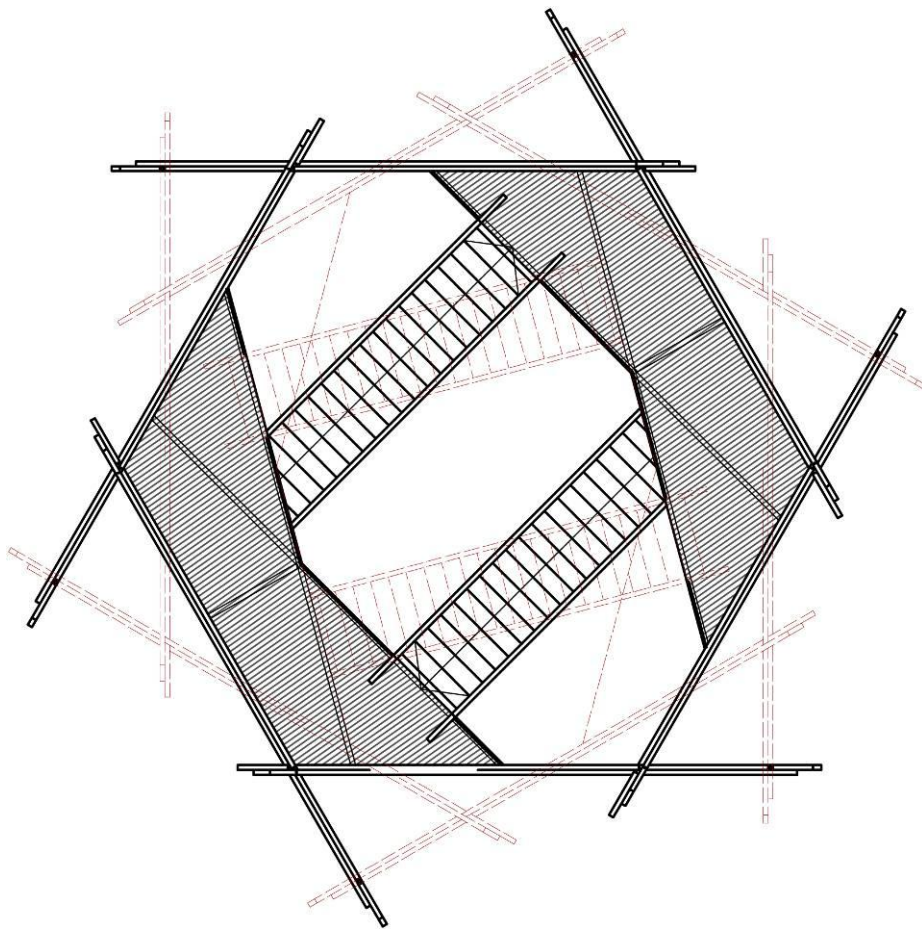


GARDE-CORPS



ESCALIERS



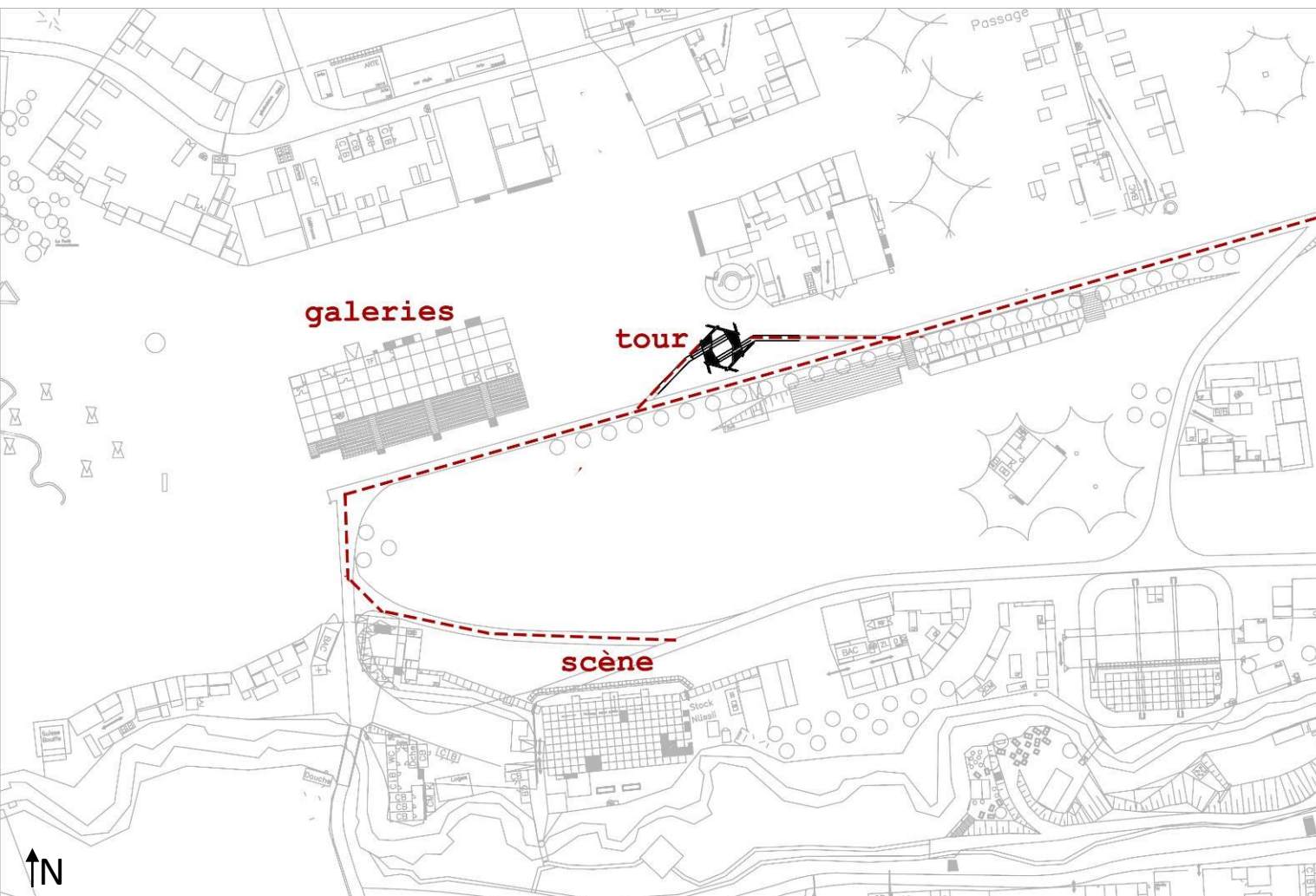


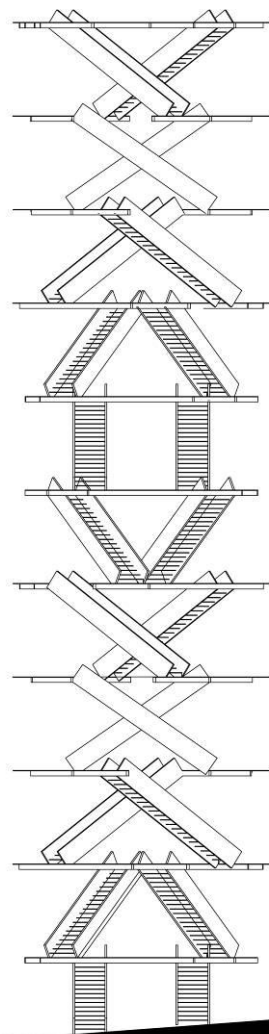
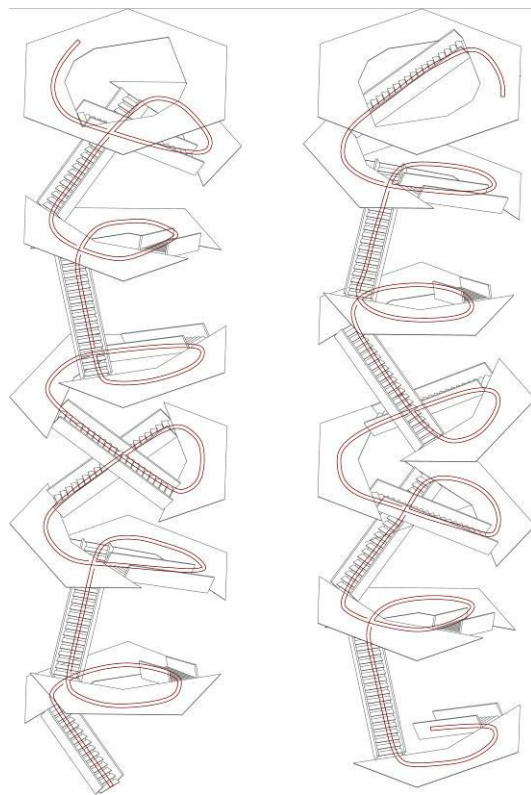
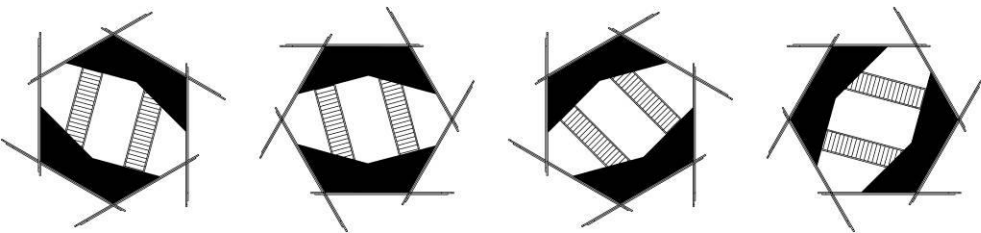
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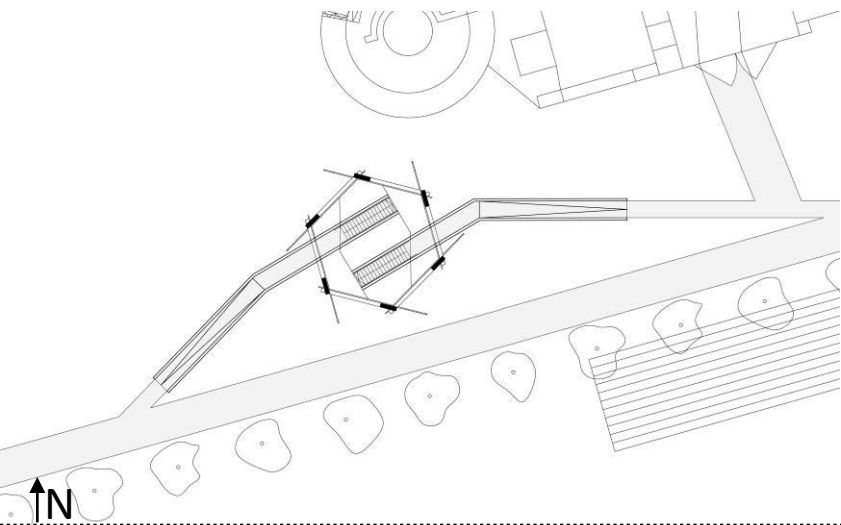
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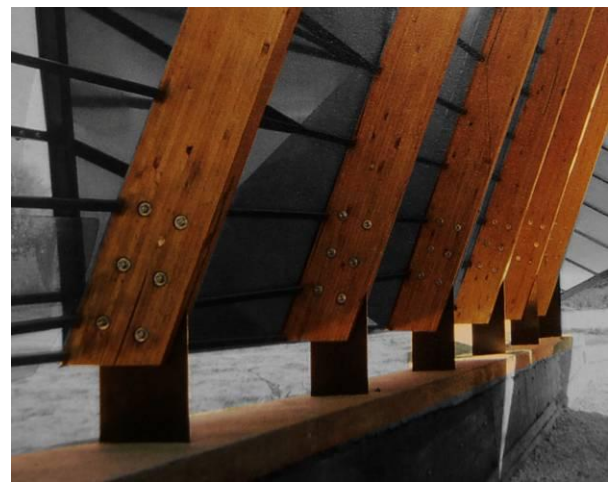
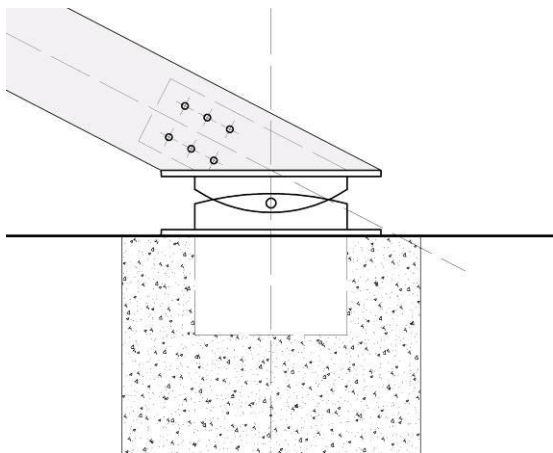


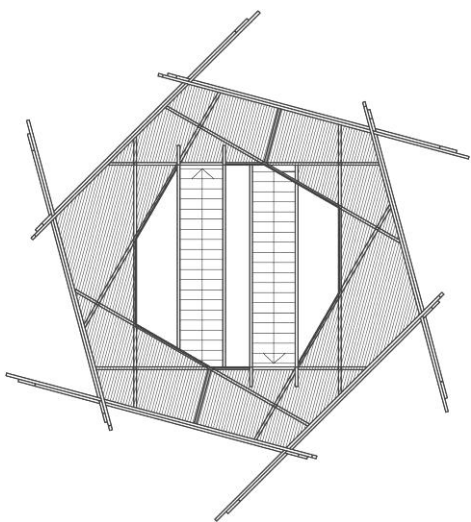


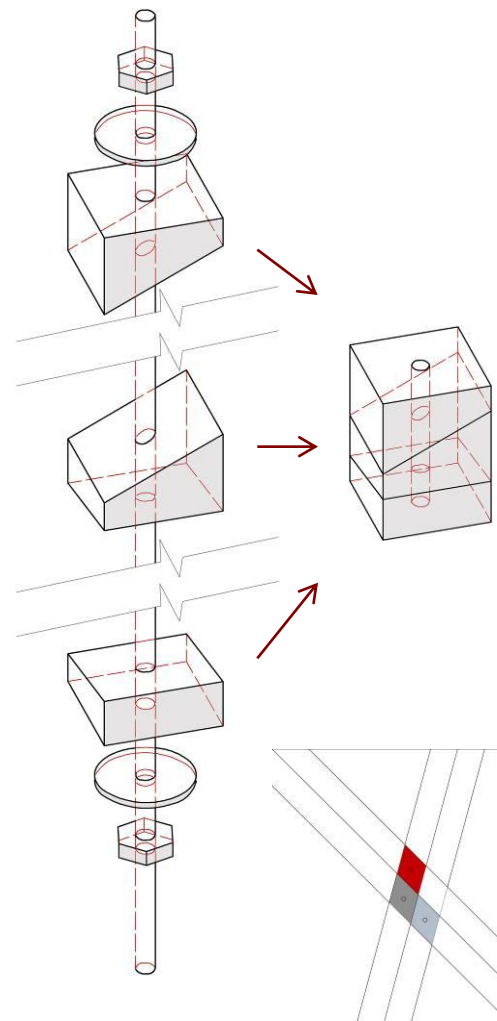
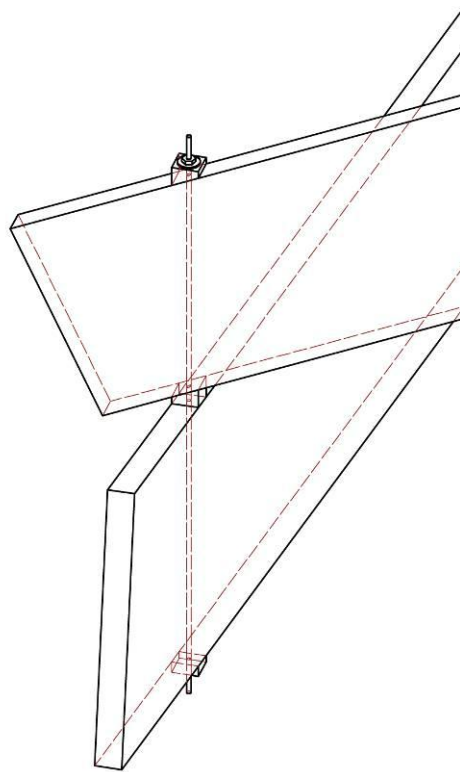
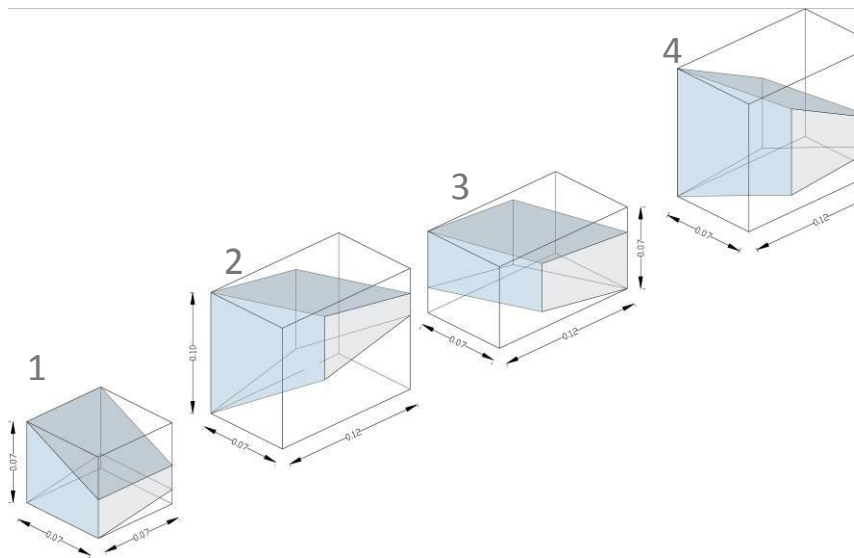


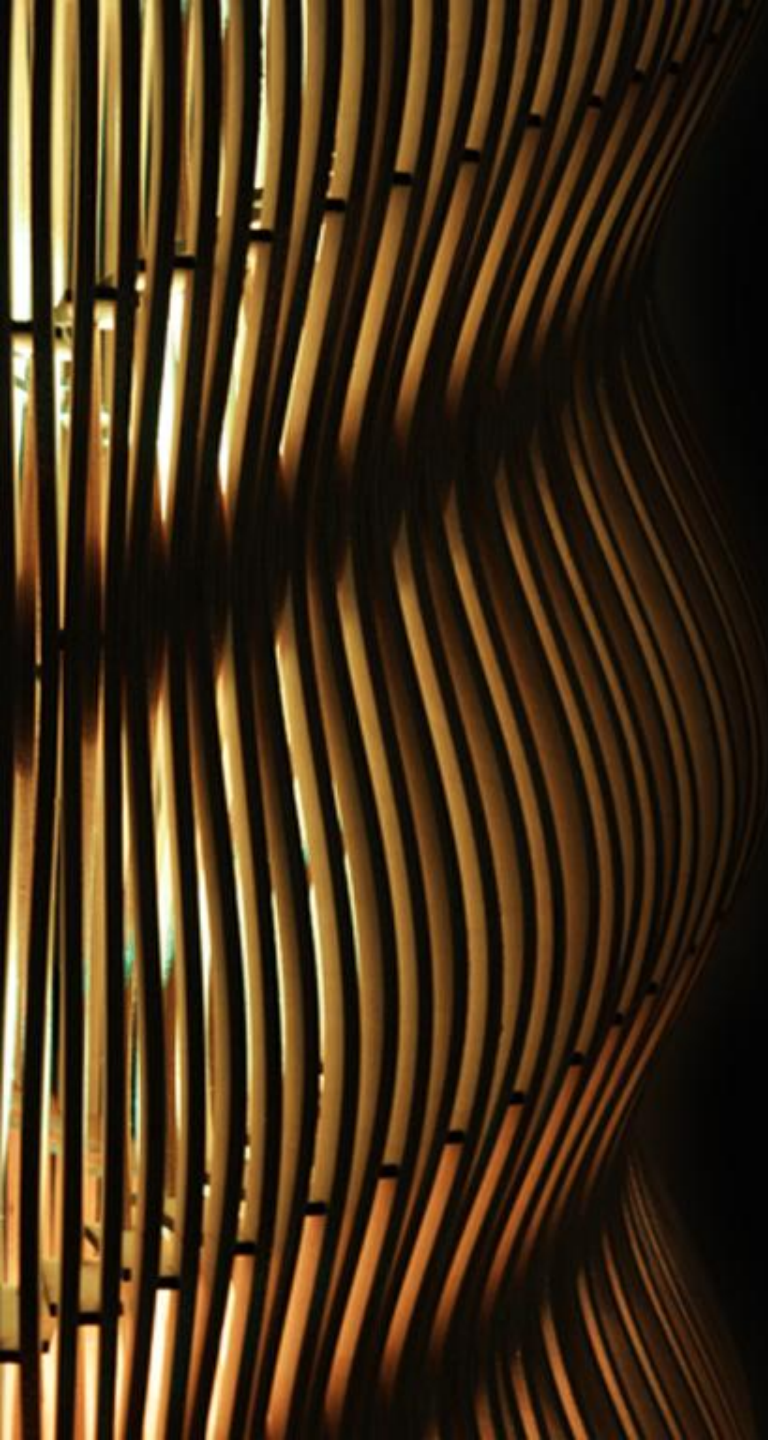
Référence

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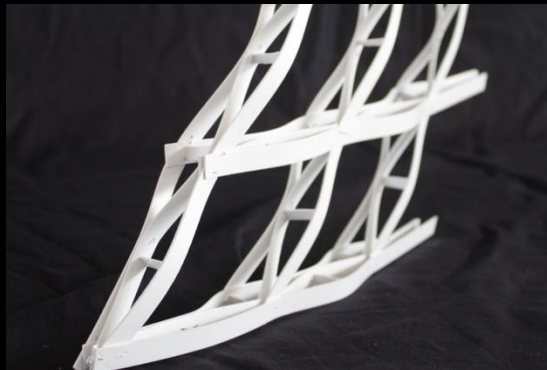
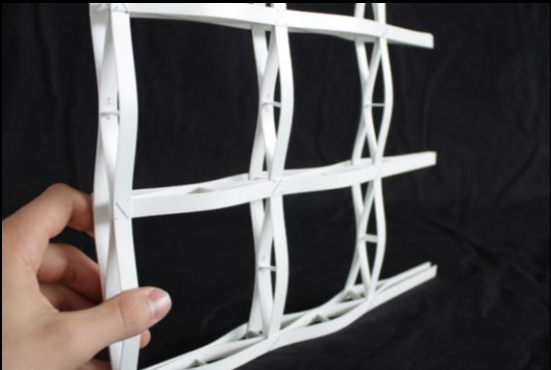
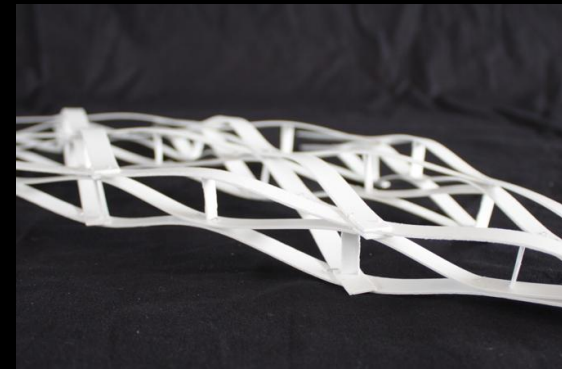
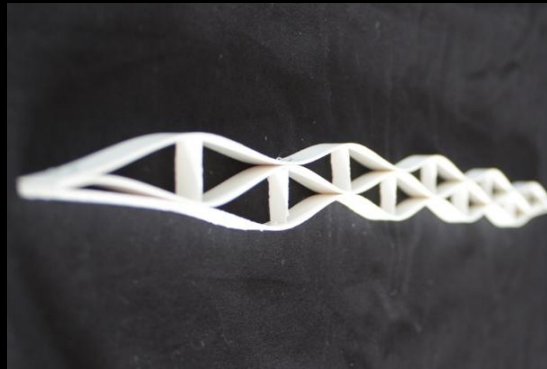
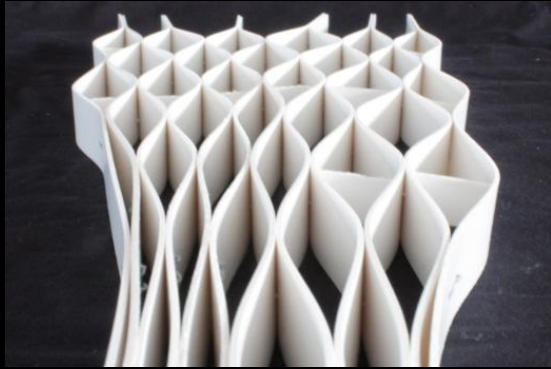




wooden waves
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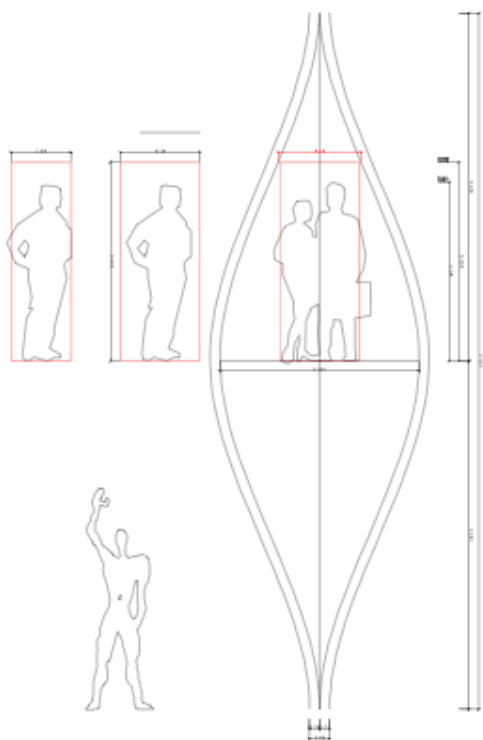


variante d'utilisation du

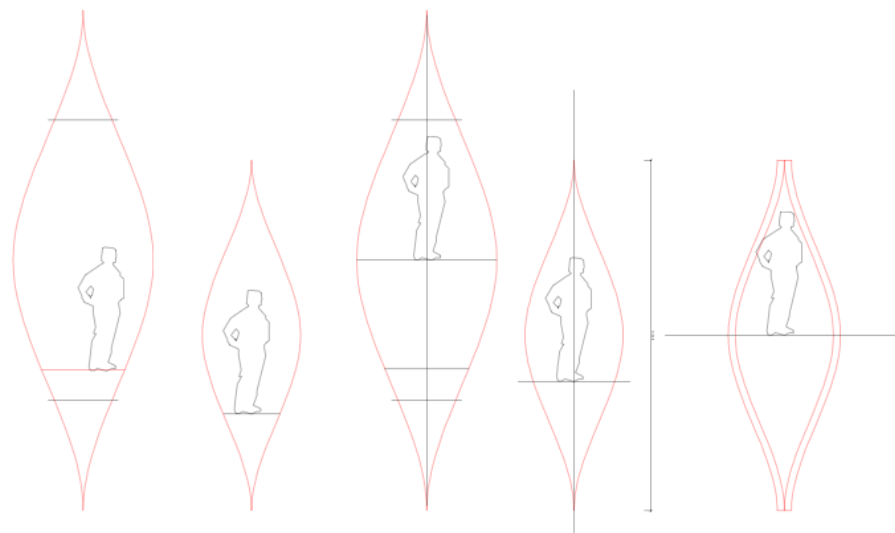
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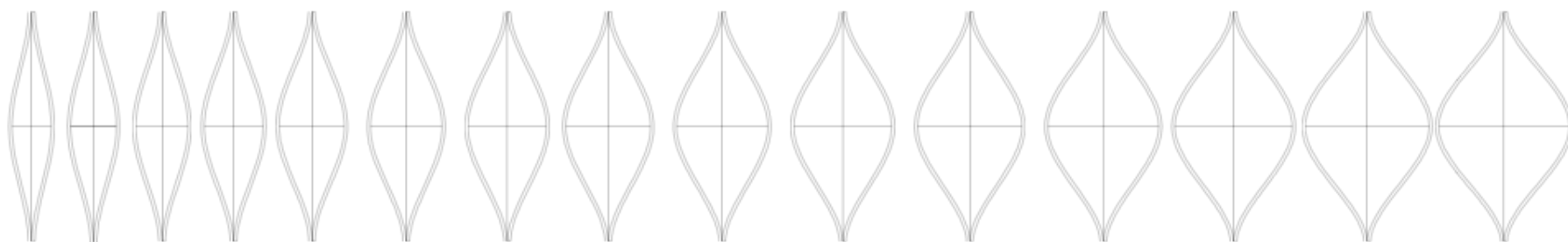




échelle du module

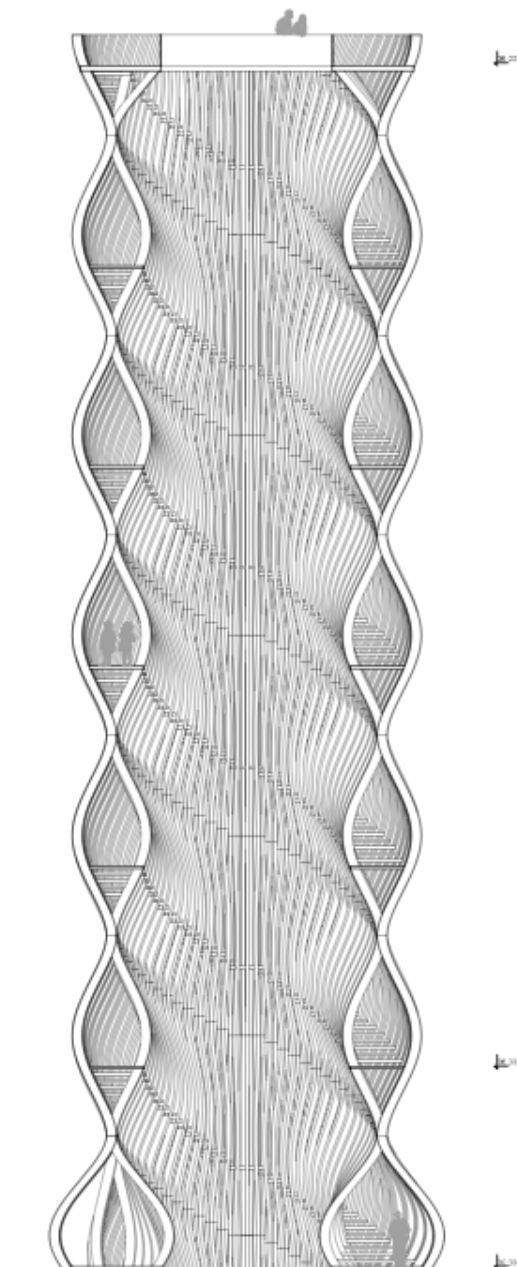


position de la marche

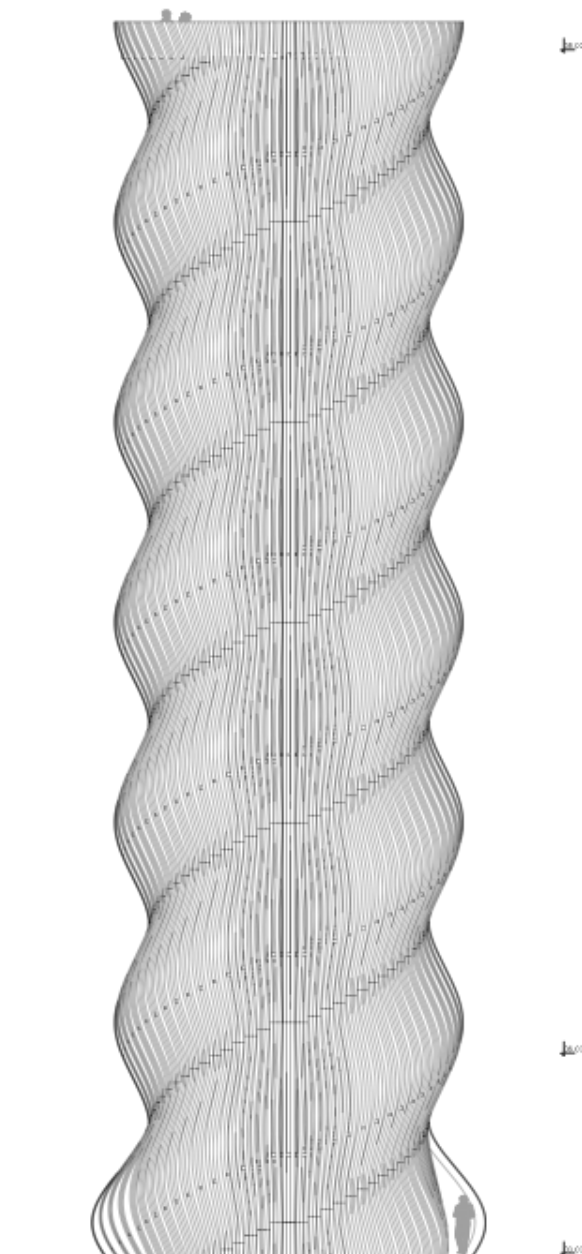


variation du module





coupe

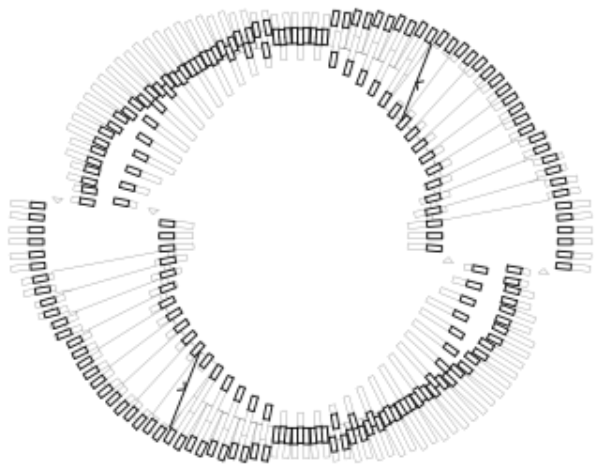


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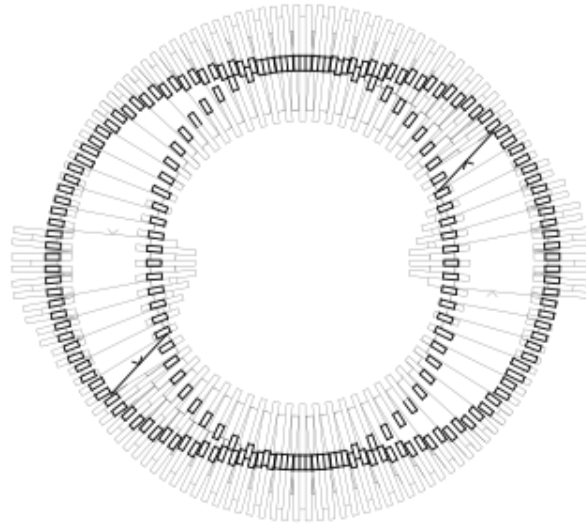
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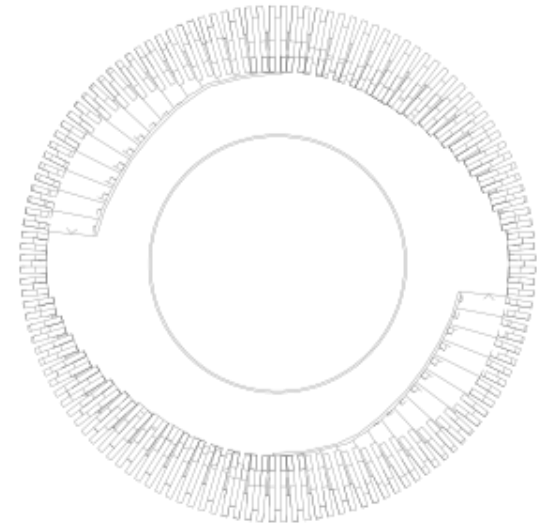




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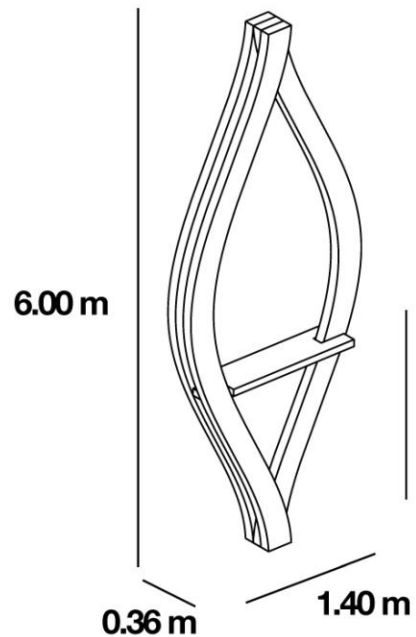


plan étage type



plan plate-forme





dimension du module

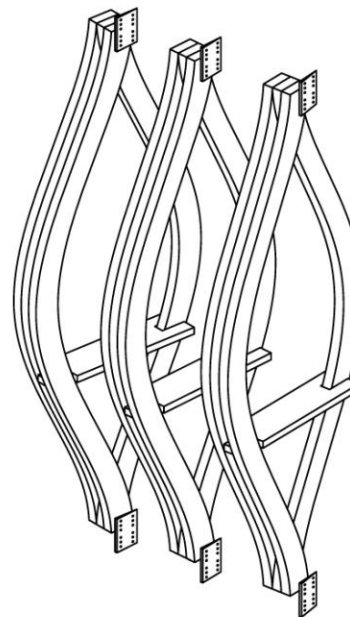


schéma assemblage

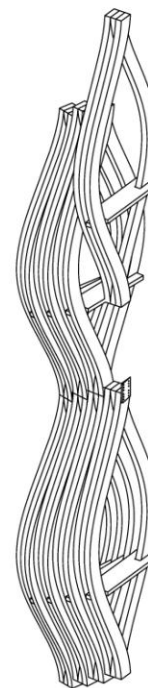
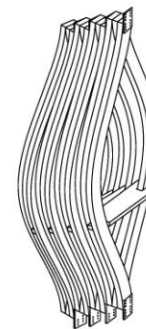
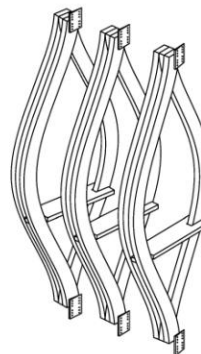
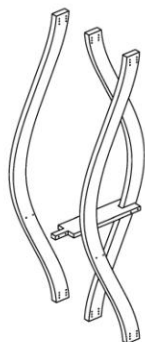
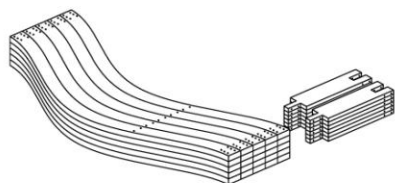
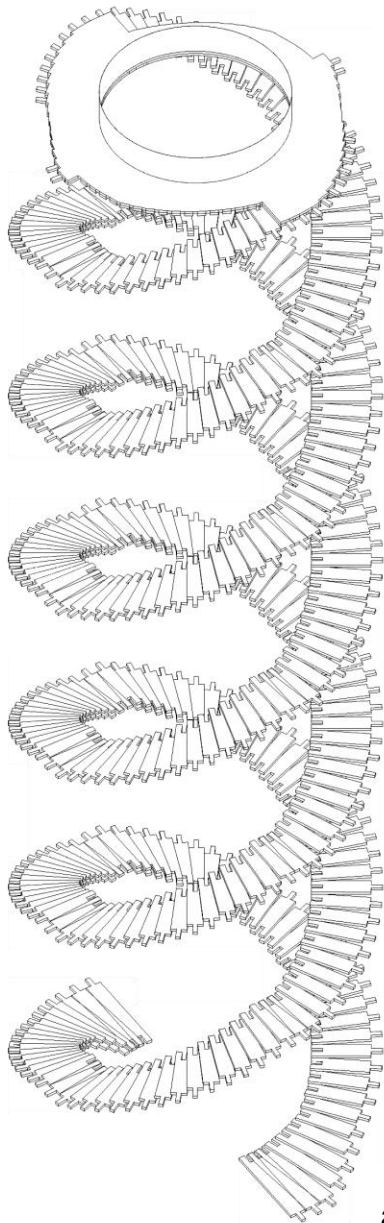
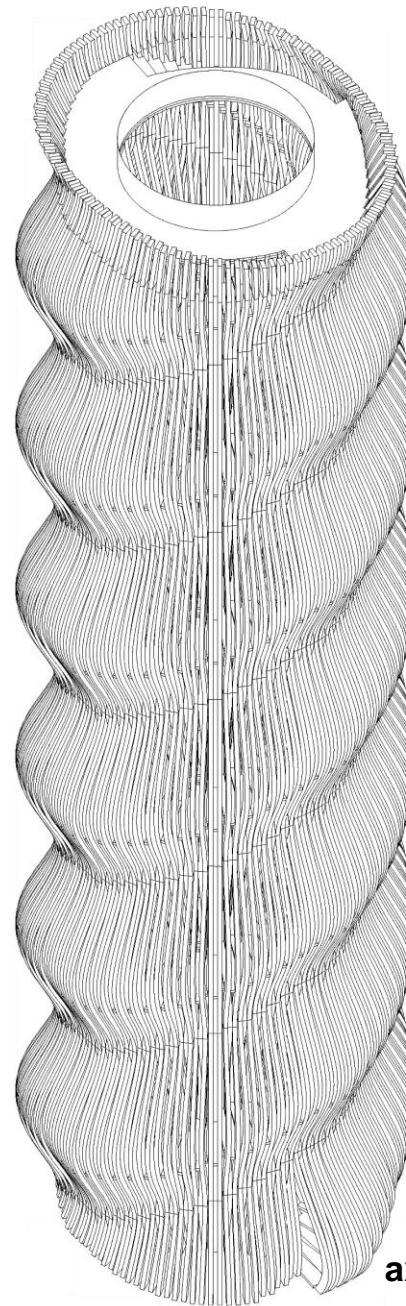


schéma assemblage



axonométrie marches



axonométrie

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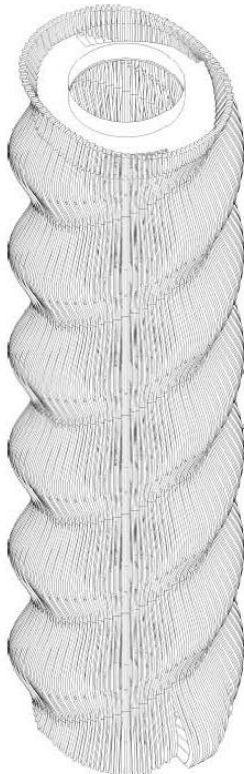




Professeur : Yves Weinand

Assistant : Sina Nabaei

Construction en bois II : Tour tressée



Étudiants :

Fares Hobeiche

Stefan Sander

1 Description du projet

Il s'agit d'une tour tressée en bois lamellé-collé d'une hauteur de 36 mètres, qui a été conçue par l'étudiant en architecture à l'EPFL Steve Cherpillod pour le Paléo Festival. La tour est constituée de deux montées hélicoïdales qui sont superposées (voir figure 1.1.). Ainsi l'une des deux spirales peut être utilisée comme montée et l'autre comme descente. Une spirale se produit avec la juxtaposition des modules qu'on voit dans la figure 1.2. Cette juxtaposition crée des vides entre les modules qui laissent entrer la lumière dans la structure. Au sommet de la tour il existe une plateforme, qui est accessible aux personnes.

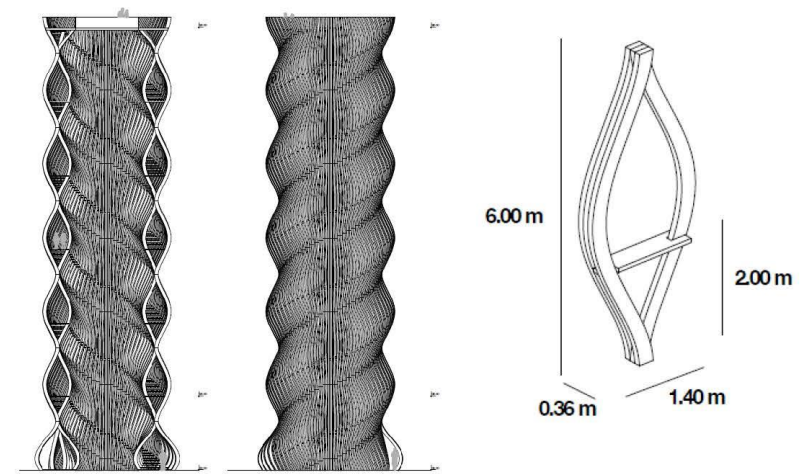


Figure 1-2: Coupe et élévation de la tour

Figure 1-1: Dimension d'un module

Tâches : Dans un premier pas il nous faut comprendre la géométrie du projet et le comportement globale de la structure sous son poids propre. Ceci peut se faire intuitivement ou à l'aide d'un logiciel 3D comme RFEM. Comme deuxième pas nous devons définir les charges de services et les charges climatiques pour analyser le comportement de la tour tressée sous ces charges. Après avoir défini tous les charges auxquelles la structure est soumise nous pouvons prédimensionner la tour et modéliser tous les détails de construction comme les assemblages, les raidisseurs etc.

1.1 Géométrie de la tour tressée

La tour en bois lamellé collé de 36 mètre de hauteur en forme de spirale est symétrique dans le plan horizontal par rapport au point central. Les deux escaliers indépendants suivent la géométrie de la tour permettent d'accéder au sommet. La structure de la tour est formée d'une série de 451 modules juxtaposés, ce qui donne la forme en spirale. Chaque module est formé de trois éléments verticaux et une marche. La courbure des éléments verticaux donne la forme spirale de la tour.

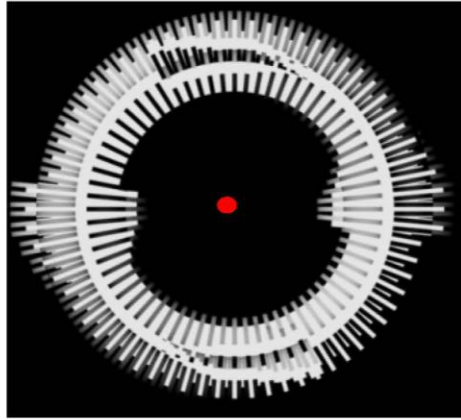


Figure 1-3: Symétrie de la tour

Poids d'un module :

Une barre courbé est constituée d'une section de 120 x 300 mm et a une longueur de 6.40 mètres. La dimension de la plupart des marches rayonnantes est 1.6 x 0.44 m avec une épaisseur de 8 cm. Ceci nous donne le poids suivant pour un module :

$$3 \text{ Barres} : 3 * 0.12m * 0.30m * 6.4m * 500 \frac{kg}{m^3} = 345.6 kg$$

$$\text{Une marche} : 1 * 1.6m * 0.44m * 0.08m * 500 \frac{kg}{m^3} = 28.2 kg$$

$$\text{Un module} : 345.6 kg + 19.2kg = 373.8 kg$$

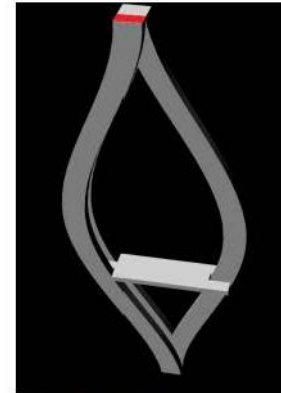


Figure 1-4 : Module à 3 barres

1.2 Subdivision de la tour par étages

La tour peut être subdivisée en 6 parties : le sommet, quatre étages centraux identiques et la base. Un étage est composé de 68 modules, alors 34 modules par spirale.

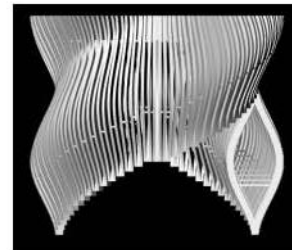


Figure 1-7: sommet de la tour

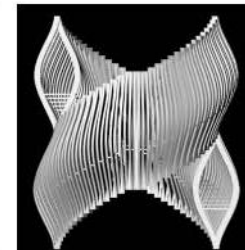


Figure 1-6 : étages centraux

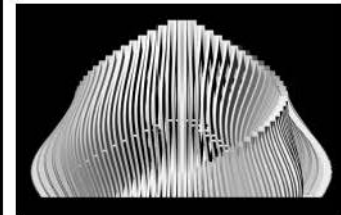


Figure 1-5 : base de la tour

Pour le prédimensionnement on va choisir des dimensions différentes pour chaque étage (voir chapitre 3).

6.2 Comparaison des efforts intérieurs de deux modules avec et sans marche

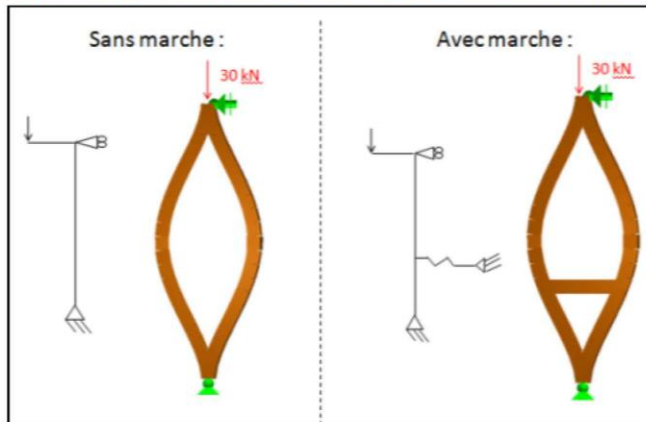


Figure 6-5 : Comparaison module avec et sans marche

On considère que les modules sont simplement appuyés à la base et sont tenu avec un appui à rouleau à la tête, comme la montre la figure ci-dessus. Les modules dans la partie inférieure de la tour subissent un effort vertical de 30 kN (voir chapitre 3.3. : Charges par étage pour un module) ce qui induit une charge de compression. La marche sera modélisé comme un appui simple ce qui rend le système hyperstatique.

6.2.1 Effort normal

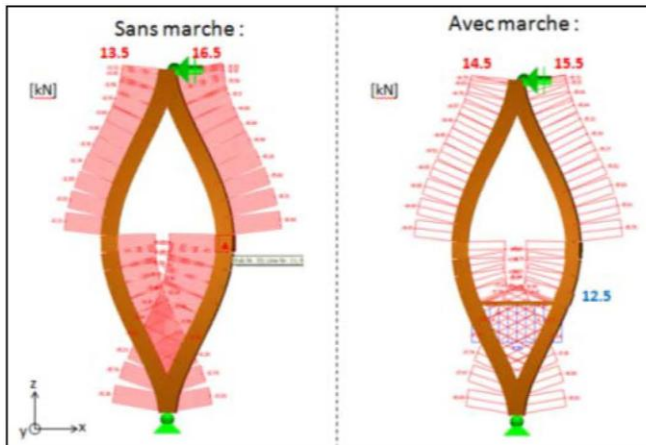


Figure 6-6 : Effort normal

La marche n'influence pas la distribution et les valeurs des efforts normaux d'une manière importante. Les forces de compression dans la barre extérieure et intérieure se harmonisent, vu que les deux barres sont liées l'une à l'autre. La force de traction dans la marche est de 12.5 kN.

6.2.2 Moment selon l'axe y

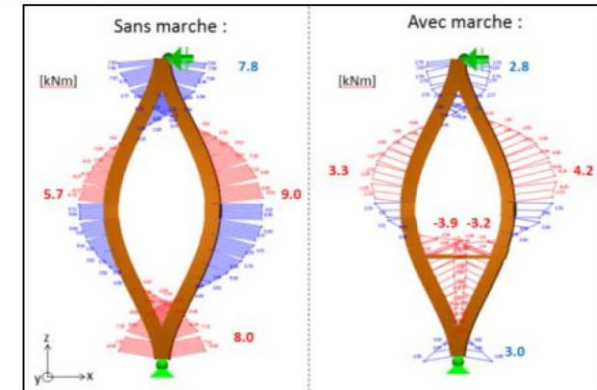


Figure 6-7 : Moment selon l'axe y

La présence de la marche réduit les moments selon l'axe y et déplace le moment maximal vers la partie supérieure de la marche. En plus la marche crée un moment négatif dans la barre à l'endroit de son appui et change le signe du moment à l'appui à la base du module.

6.2.3 Déformation latérale

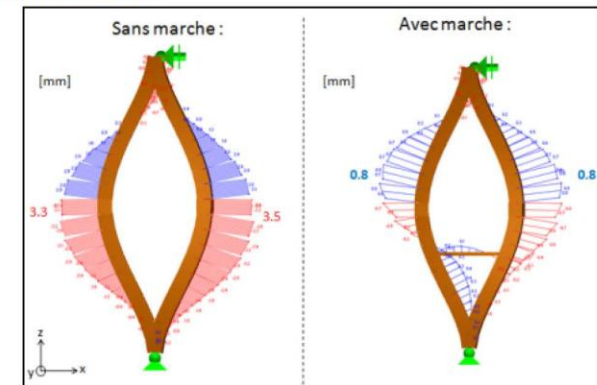


Figure 6-8 : Déformation latérale

La présence de la marche réduit les déformations latérales d'une ampleur importante. On peut observer une courbure de la marche vers le haut et un changement de la direction de la déformation dans la barre à l'intérieur.

7 Modélisation sur RFEM de la tour initiale

7.1 Introduction de la structure

7.1.1 Barres intérieures



Figure 7-1 : Sections des barres intérieures

7.1.2 Barres extérieures



Figure 7-2 : Sections des barres extérieures

7.1.3 Marches

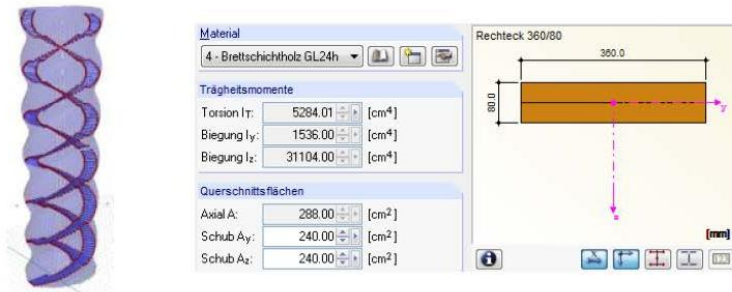


Figure 7-3 : Sections des marches

7.1.4 Spirales

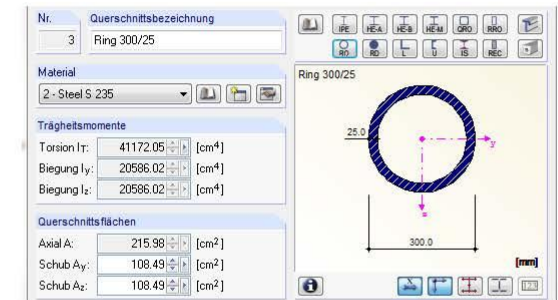


Figure 7-4 : Section des deux spirales

Les spirales servent à la tour comme contreventement, comme le schéma suivant nous le montre.

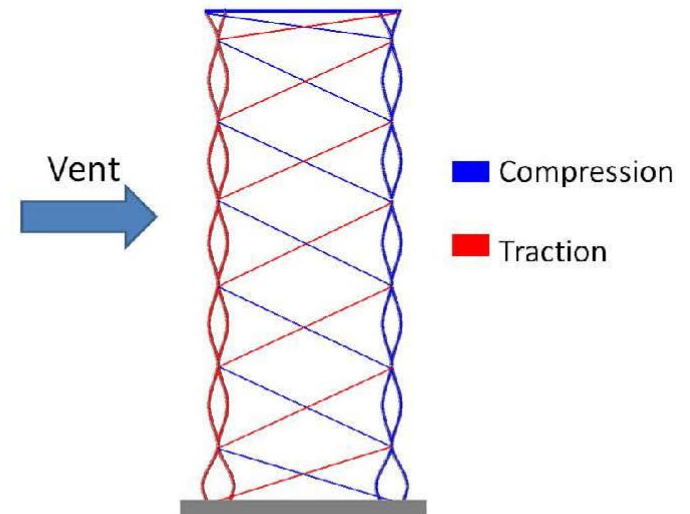


Figure 7-5 : Système de contreventement des spirales

7.2 Application des charges

7.2.1 Poids propre

Le poids propre est directement calculé par RFEM en fonction du volume des éléments.



Figure 7-8 : Application du poids propre dans RFEM

7.2.2 Charge utile

7.2.2.1 Marches

Avec une charge utile de 5 kN/m^2 et une largeur générale de 0.44 m d'une marche on arrive à une charge linéaire de 2.2 kN/m par marche.

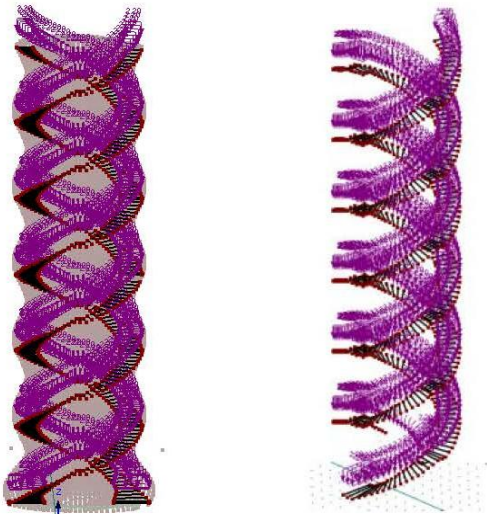


Figure 7-9 : Application charge utile dans RFEM - marches

7.2.2.2 Plateforme

Sur la plateforme on applique une charge répartie ponctuellement sur les 222 nœuds de la dalle. La surface totale de la plateforme est de 30 m^2 , on trouve alors une force de $30\text{ m}^2 * 5\text{ kN/m}^2$ divisé par $222 = 0.68\text{ kN}$ par nœud

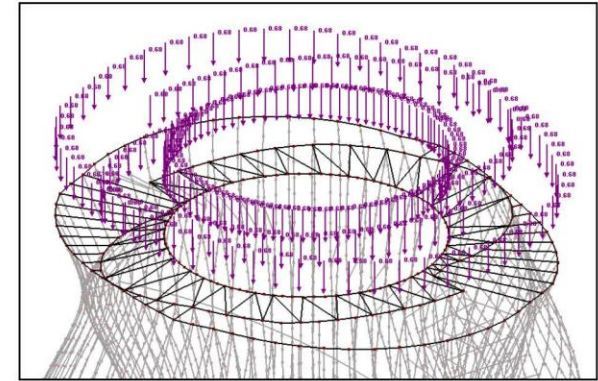


Figure 7-10 : Application charge utile dans RFEM - plateforme

7.2.3 Neige

De la même manière comme pour la charge utile, on peut introduire la charge de neige dans RFEM:

$30\text{ m}^2 * 0.74\text{ kN/m}^2$ divisé par $222 = 0,1\text{ kN}$ par nœud

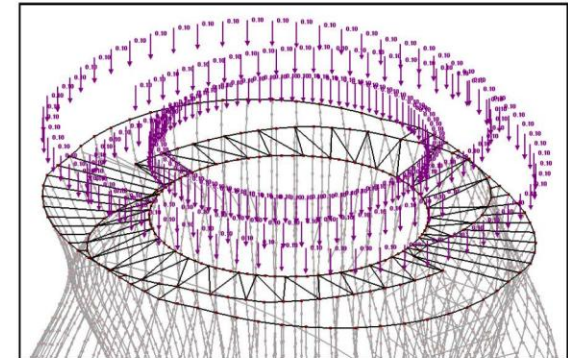


Figure 7-11 : Application charge de neige dans RFEM

9.4 Vérifications

9.4.1 Flambage de la barre

La vérification du flambage se trouve en annexe 11.5 et s'est fait en tenant compte de la marche. La longueur de flambage pour l'axe y est alors réduite à une valeur de 4.4 m.

La section de 200x450mm est suffisante.

9.4.2 Vérification des spirales

Une vérification des spirales n'est pas faite dans le cadre de ce travail.

9.4.3 Assemblage entre les modules

9.4.3.1 Variante 1 – spirale à l'intérieur

On propose un assemblage avec des boulons ajustés et deux tôles extérieures en acier (profile U), les tôles seront soudées à la spirale.

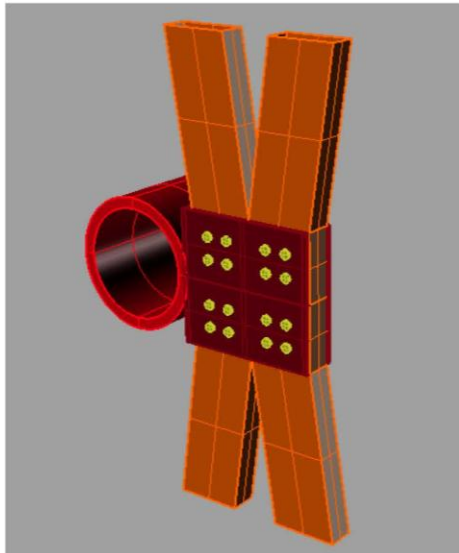


Figure 9-17 : Schéma de l'assemblage entre les modules – Variante 1

Pour trouver l'effort ($F_{d,max}$) déterminant pour le cisaillement des boulons on procède de la manière suivante :

On considère que la compression est transmise directement par le bois, tandis que la traction est reprise par cisaillement à travers les boulons. Pour être conservatif on néglige les efforts de compression. $F_{d,max}$ est l'effort en biais dans les deux plans de cisaillements (horizontale / verticale) entre une barre en bois et les deux tôles en acier.

9.4.3.2 Variante 2 – spirale au milieu des deux modules

L'assemblage de la variante 2 est constitué d'une tôle en acier au milieu des barres qui les tient à l'aide des boulons, les tôles seront soudées à la spirale, qui elle, se trouve au milieu des deux modules.

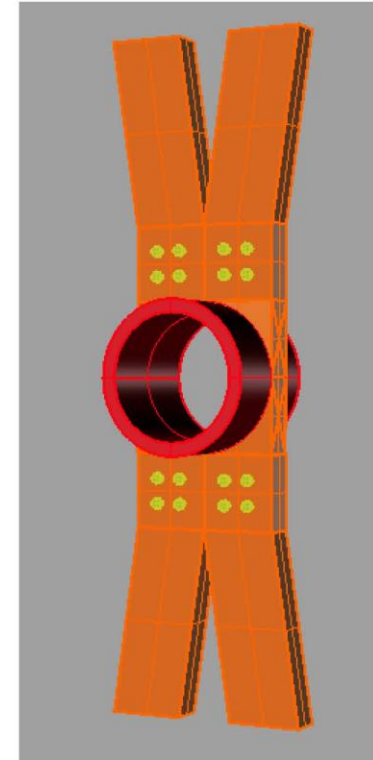


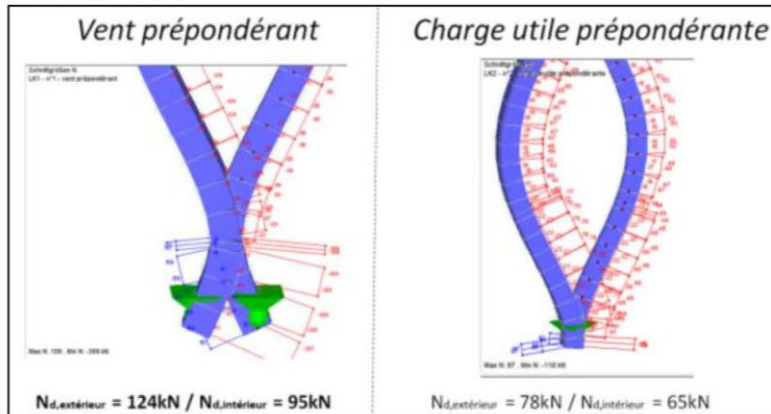
Figure 9-21 : Schéma de l'assemblage entre les modules – Variante 2

Les vérifications pour cette variante 2 se font de la même manière que pour la variante 1.

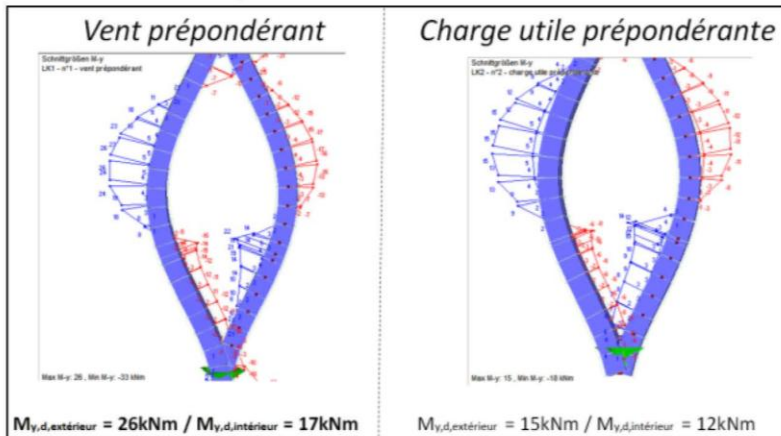
11.2 Tour initiale – Graphes RFEM

11.2.1 Efforts maximaux dans les barres

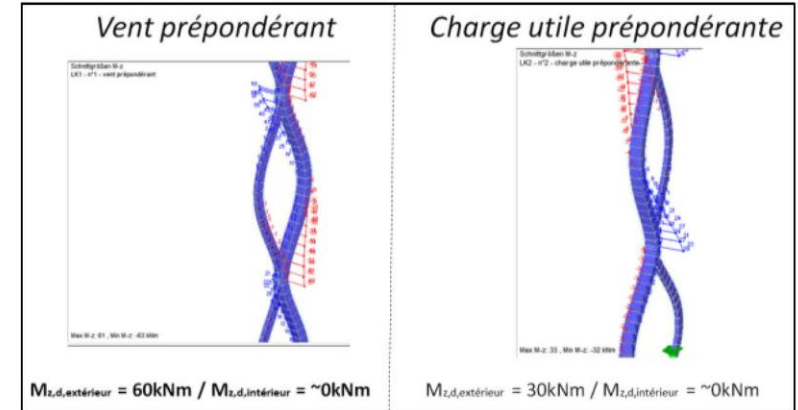
11.2.1.1 Effort normal

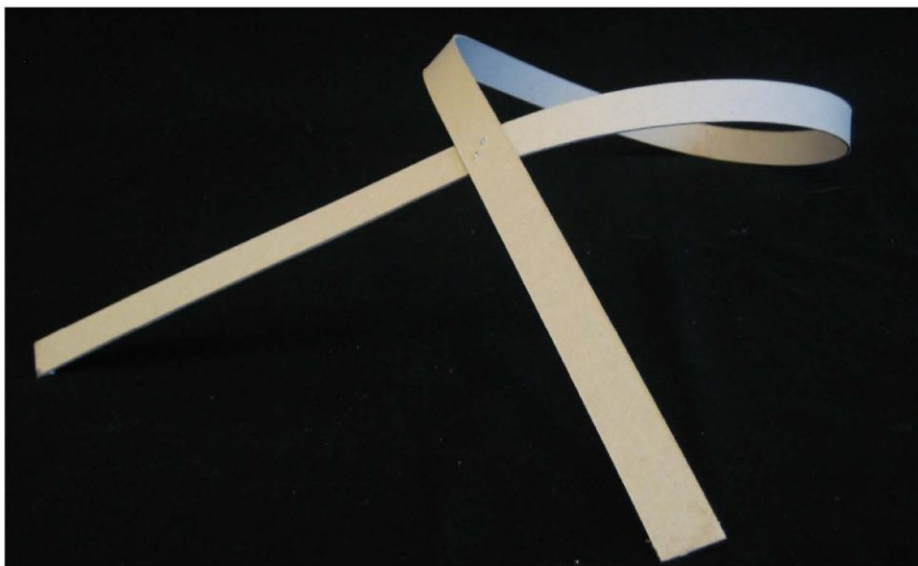


11.2.1.2 Moment selon l'axe y



11.2.1.3 Moment selon l'axe z

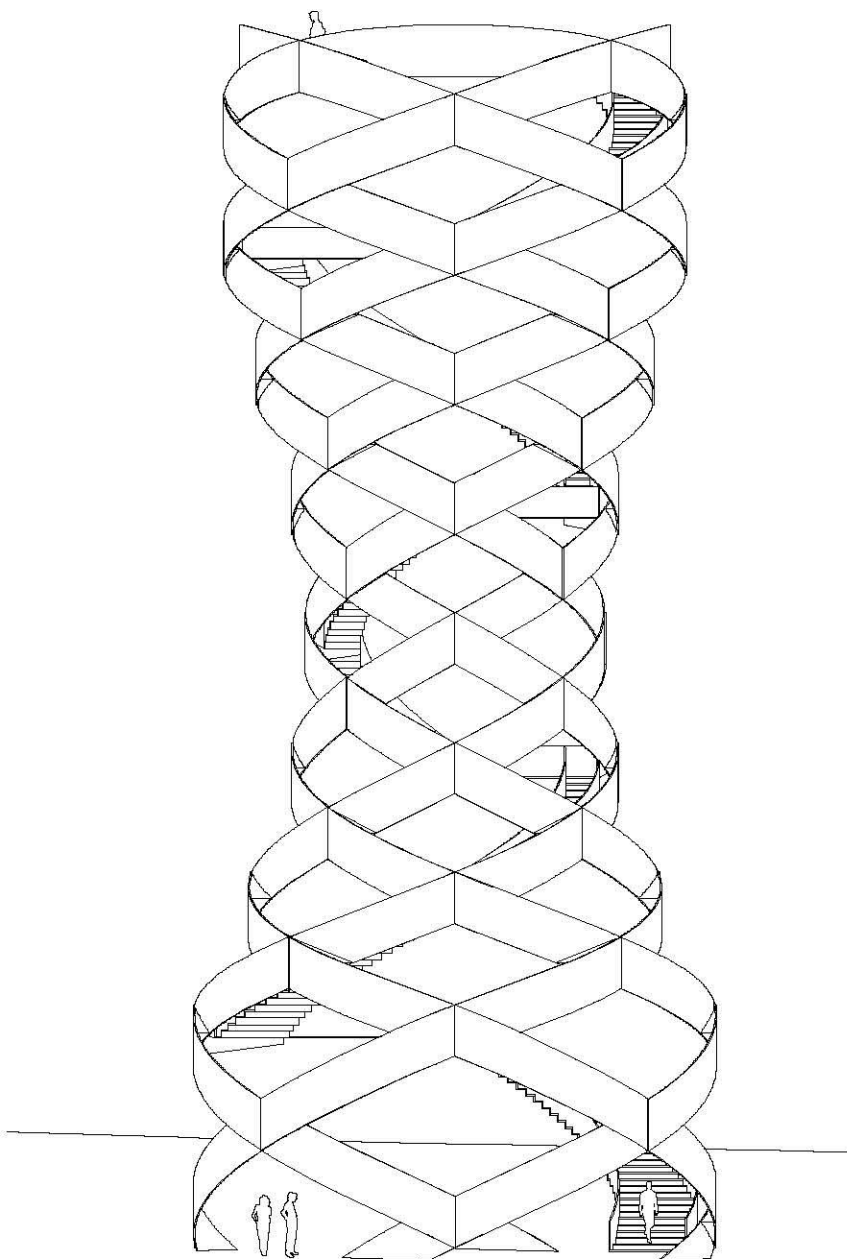




EXERCICE PRELIMINAIRE

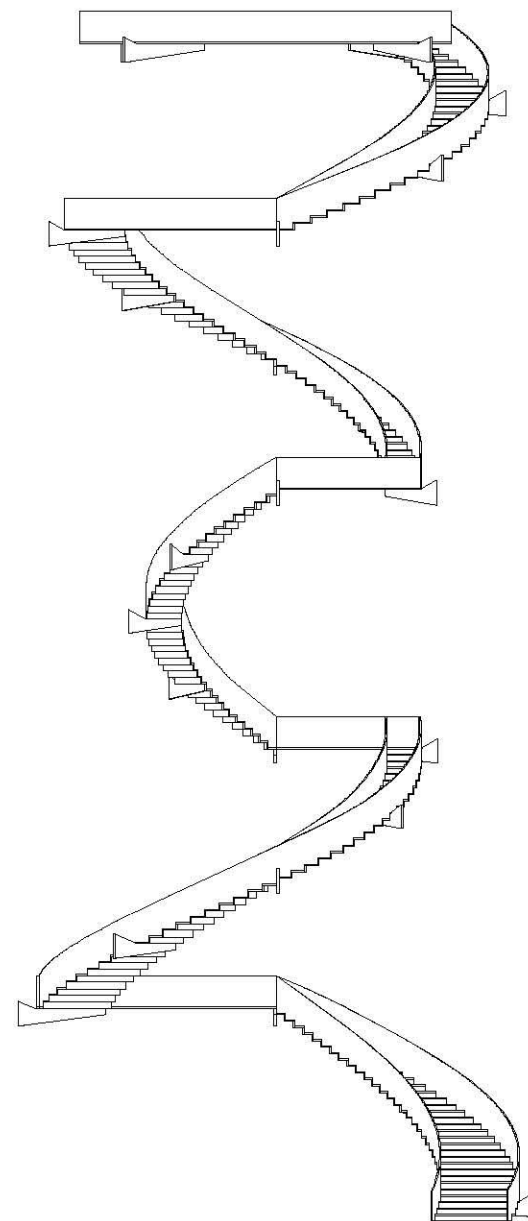


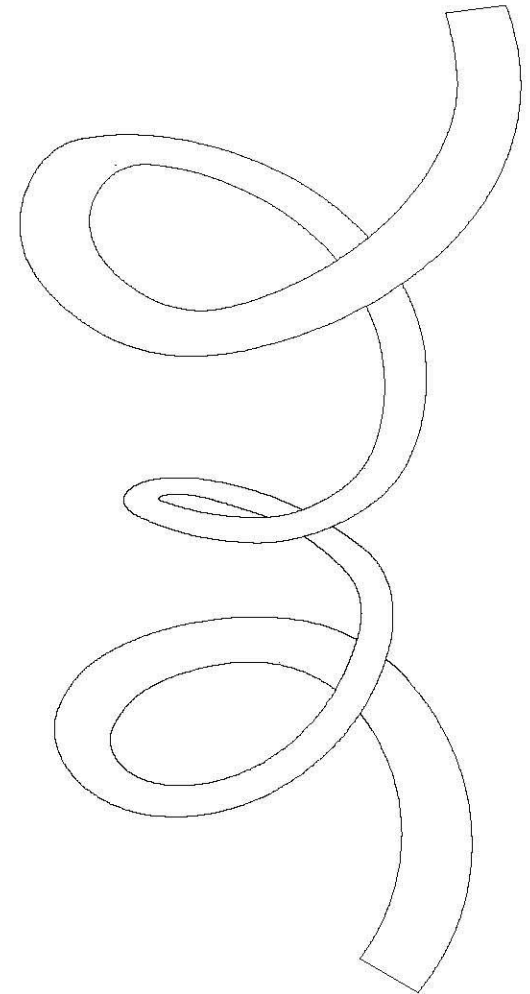
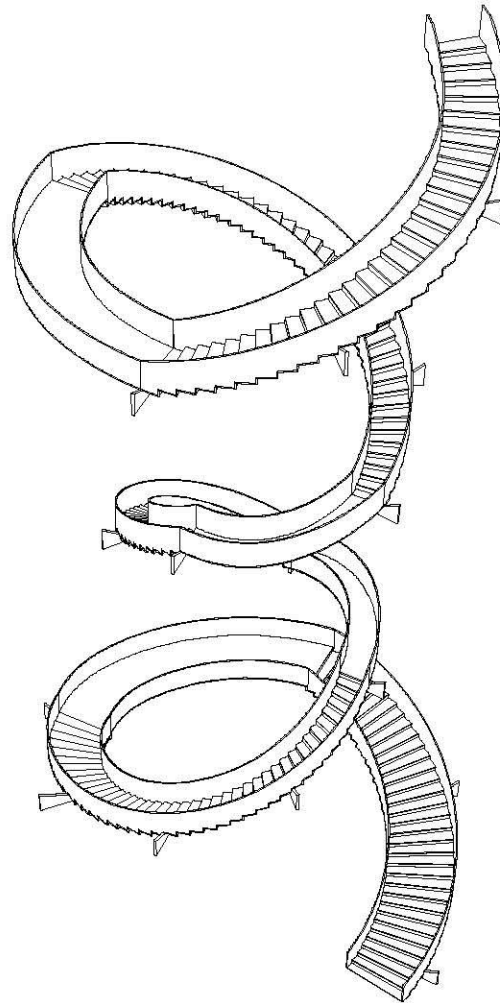
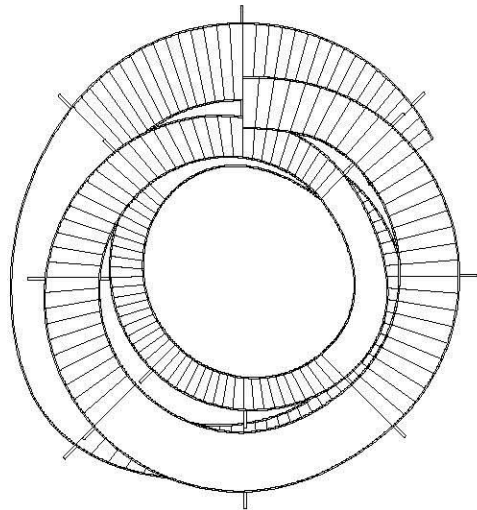
DEVELOPPEMENT DES MAQUETTES



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ELEVATION SUD - EST

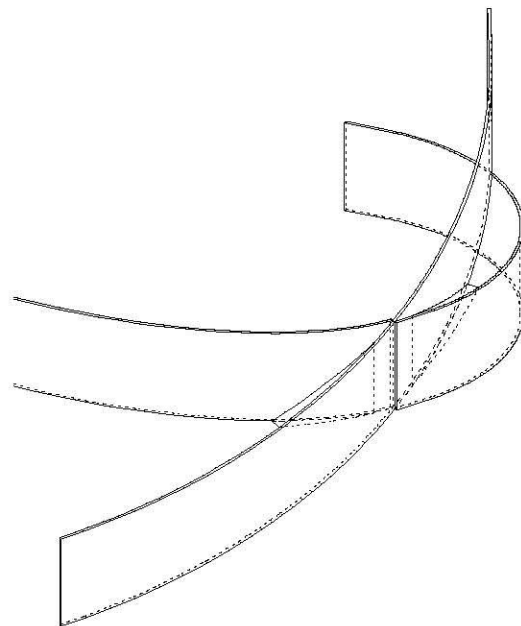
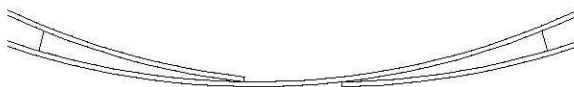
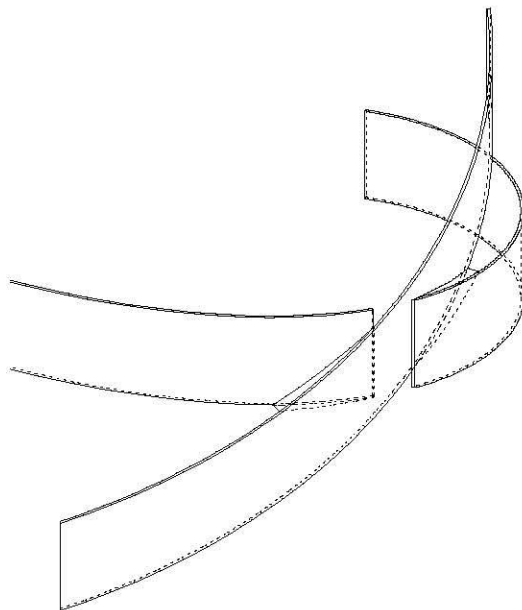
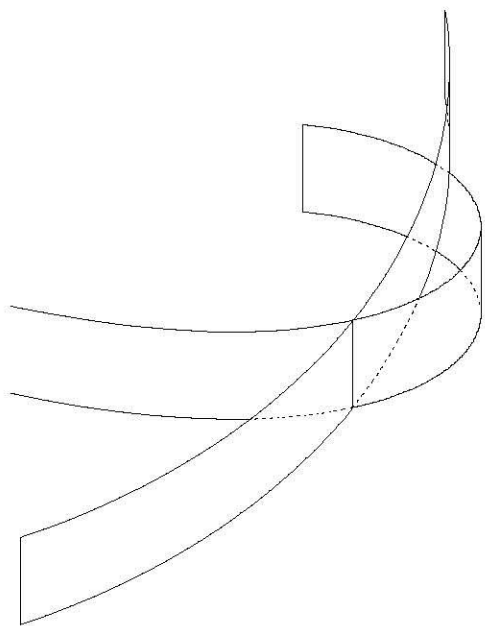




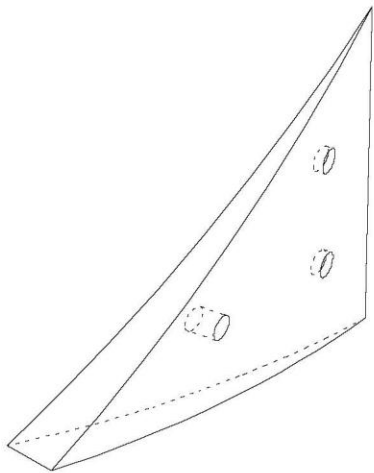
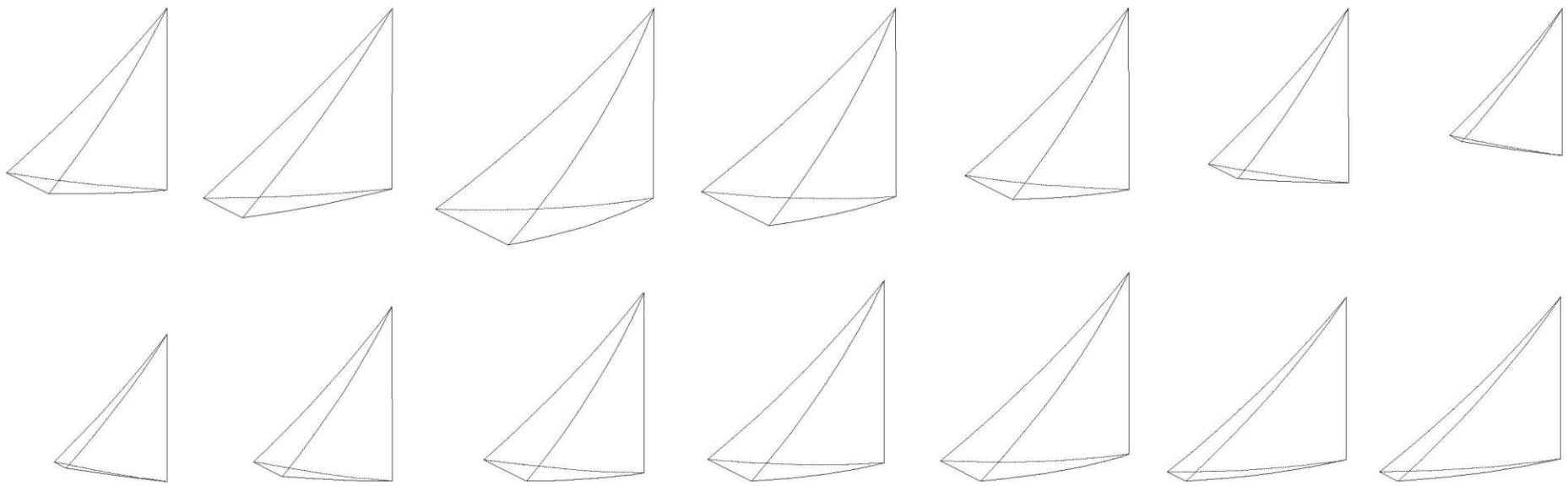
ESCALIER



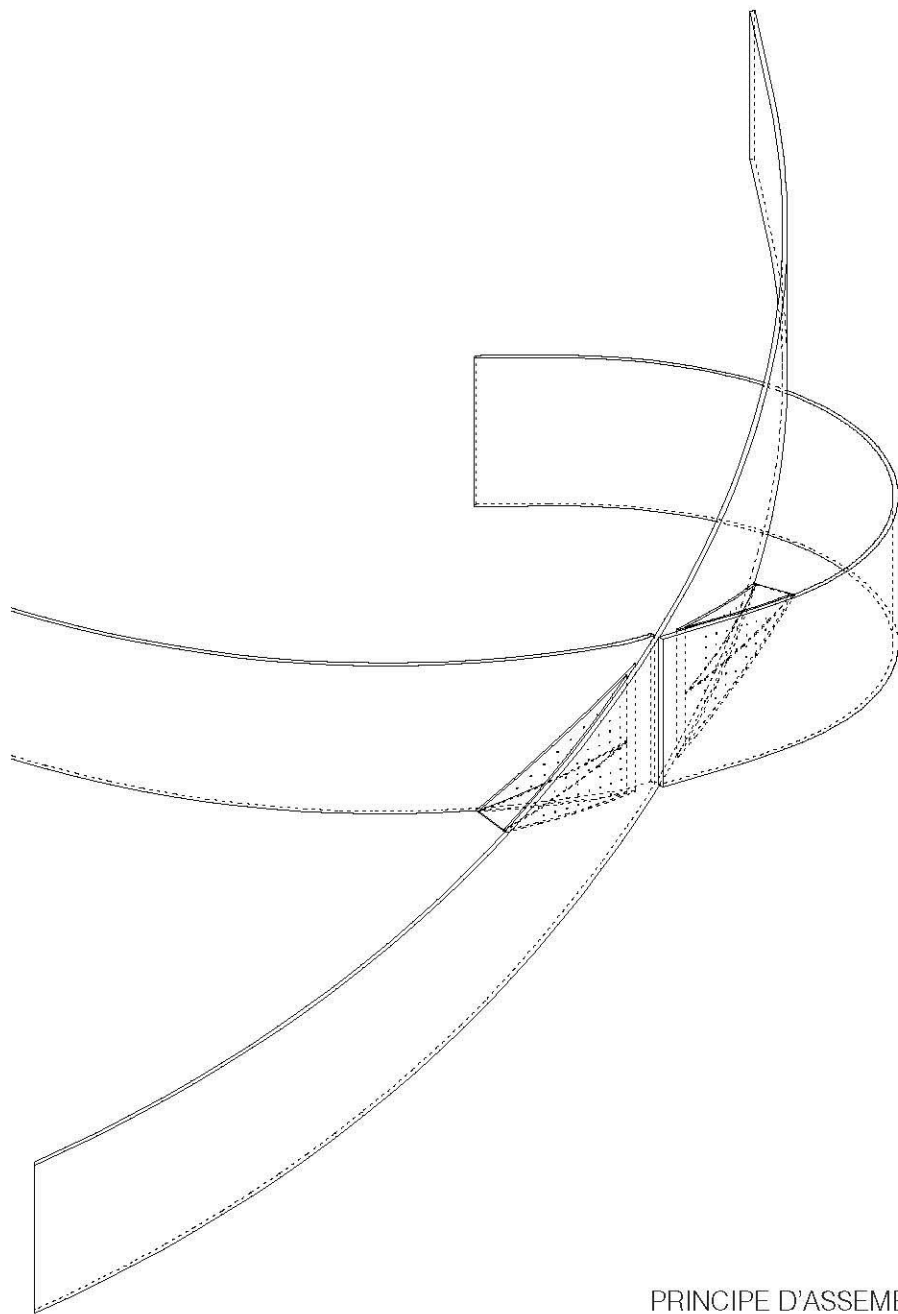
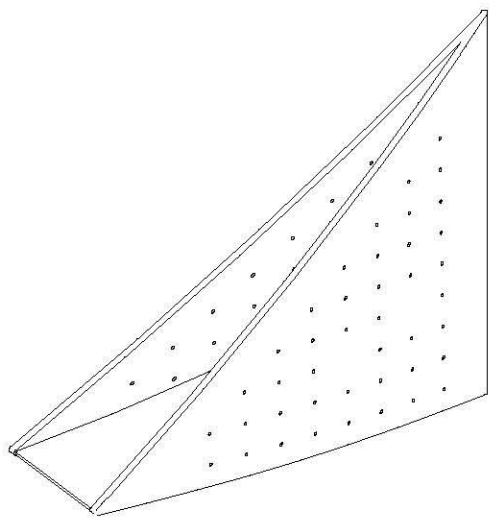
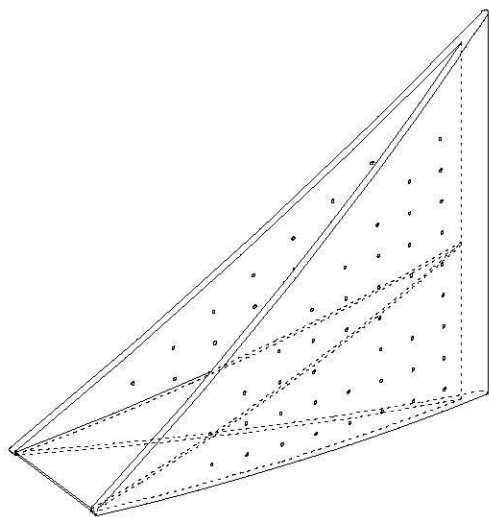




PRINCIPE D'ASSEMBLAGE



PRINCIPE D'ASSEMBLAGE

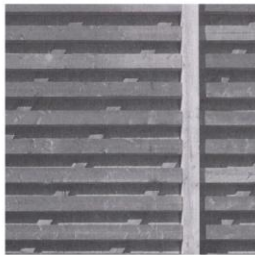
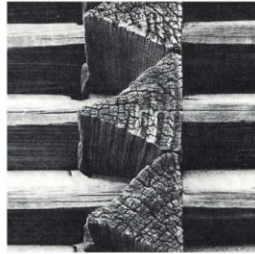
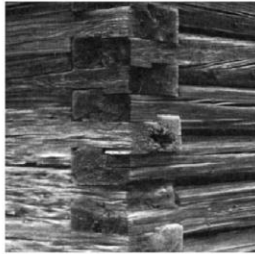


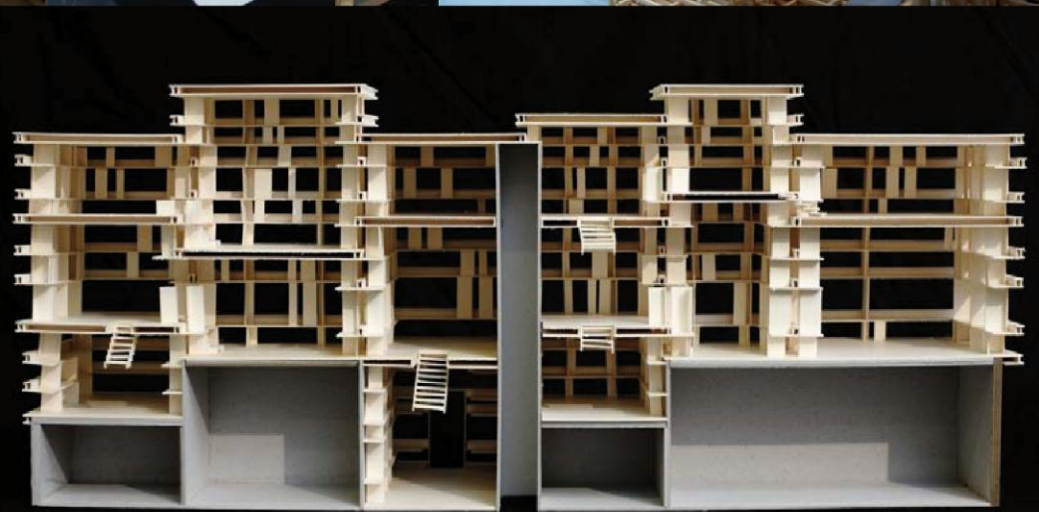
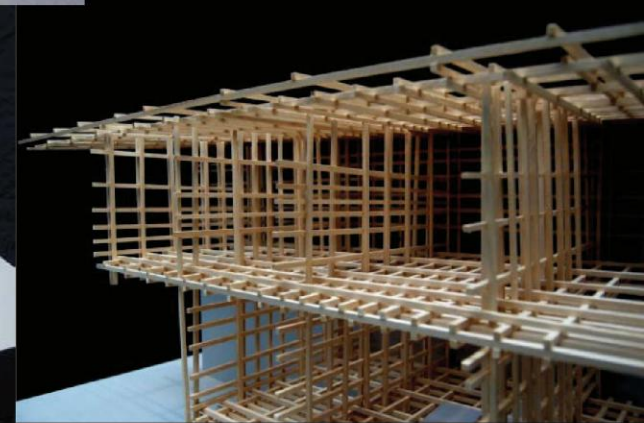
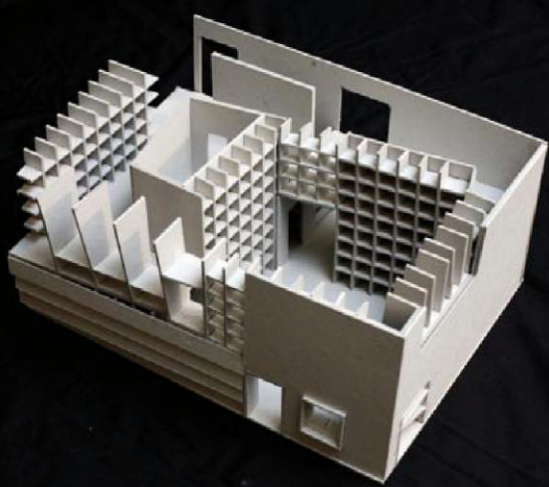
PRINCIPE D'ASSEMBLAGE



Plan de la ville de Polignac, de Côté du Sud avec les montagnes qui y a à son Nord.

Student Work





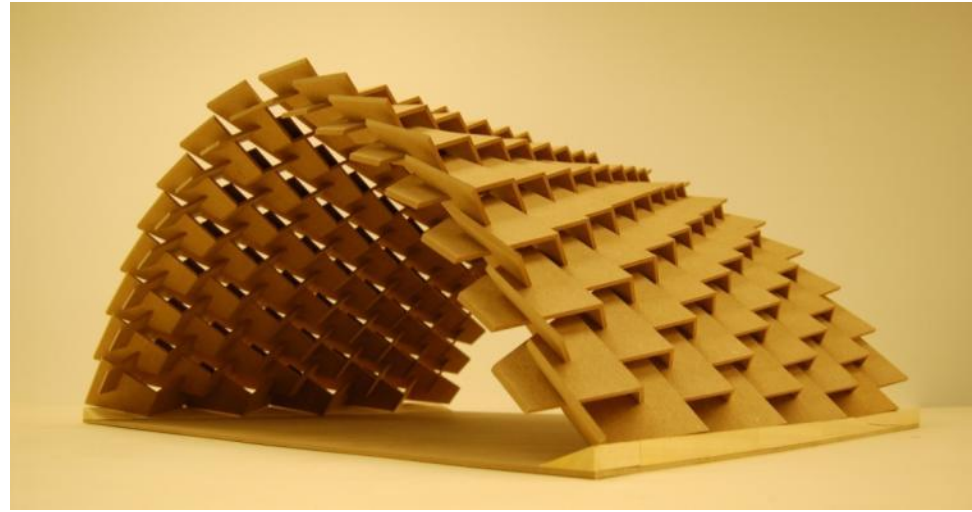
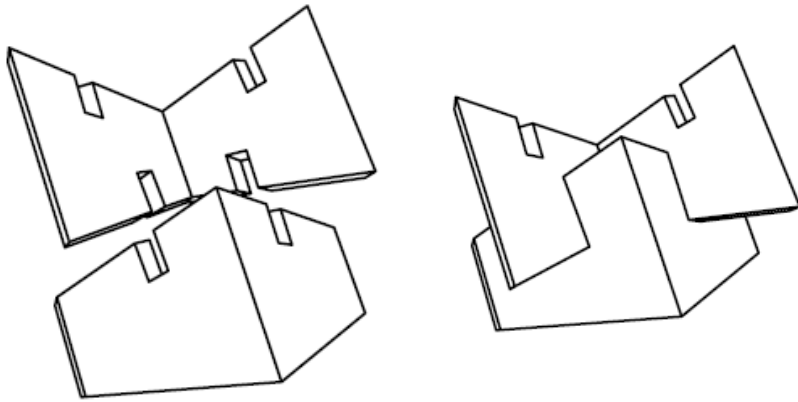


Student Work



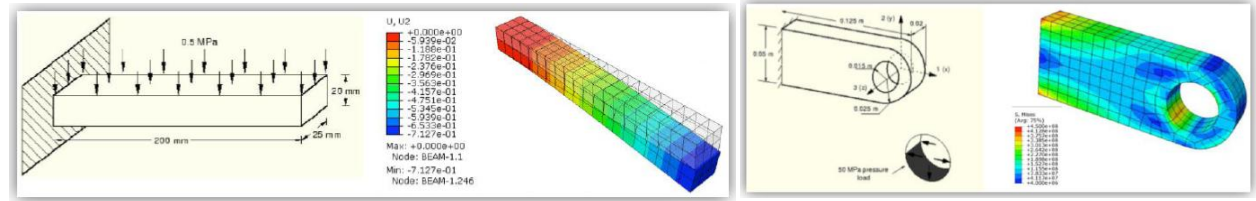
A MODULAR TIMBER STRUCTURE:

Case study of a project from IBOIS : Two approaches

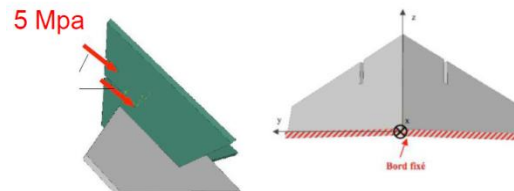


Project 4 credits

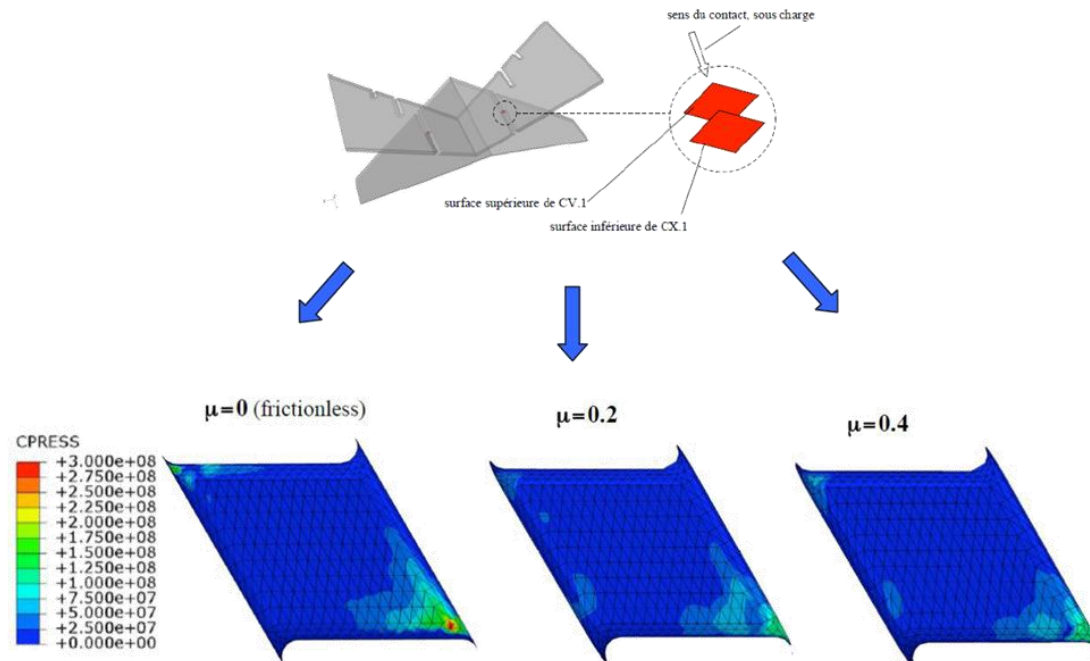
Software training (ABAQUS)



Interaction of two modules

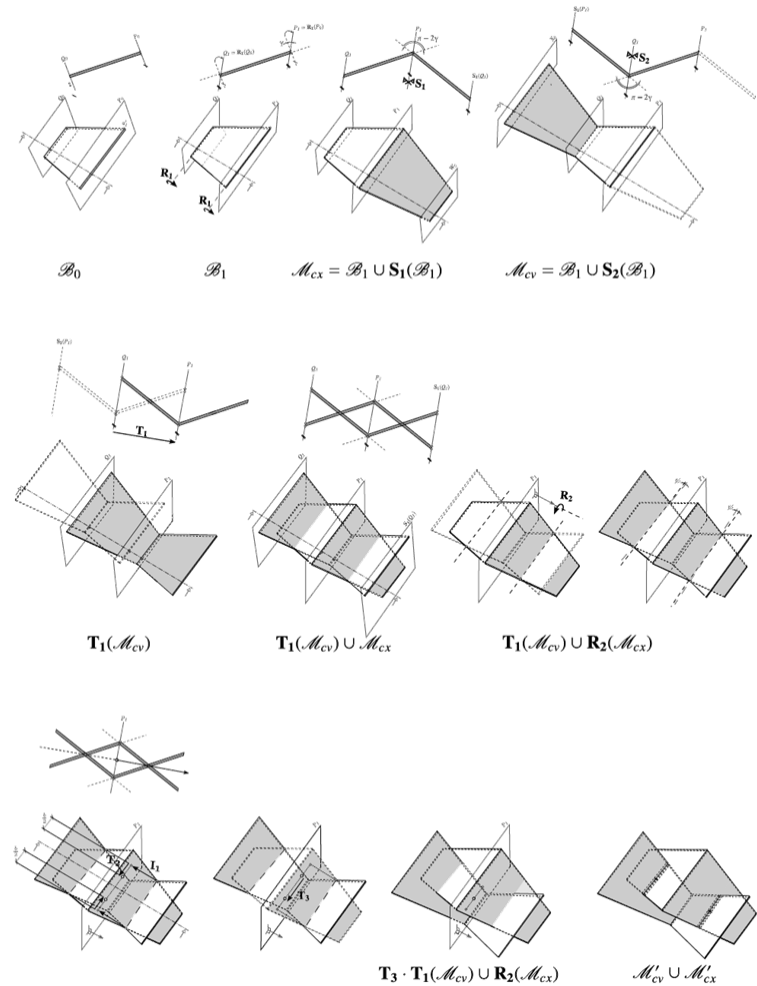


Results



Project 8 credits

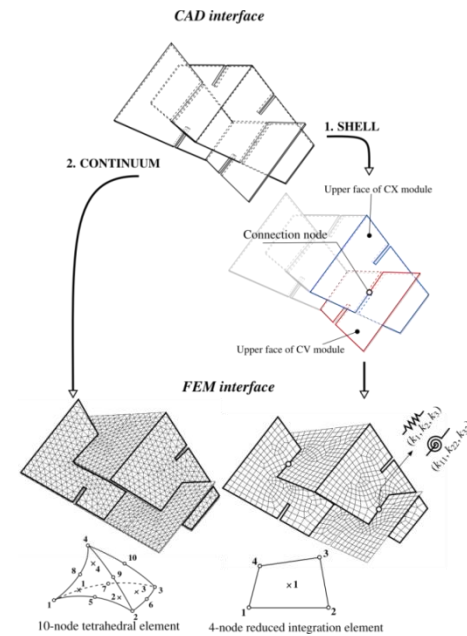
Geometrical decomposition and parametric design



Sina Nabaei

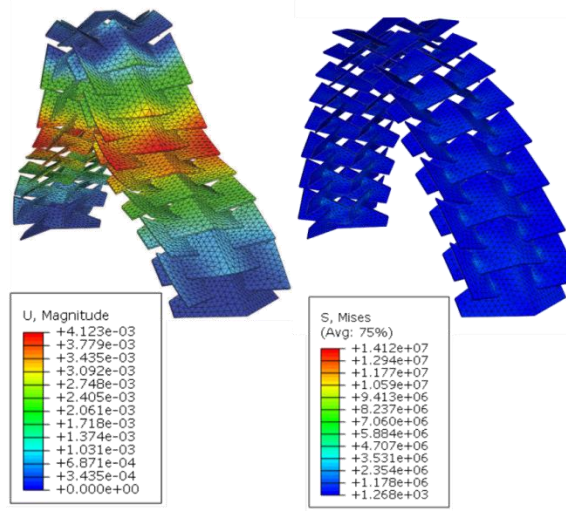
Future Teaching

FEM analysis

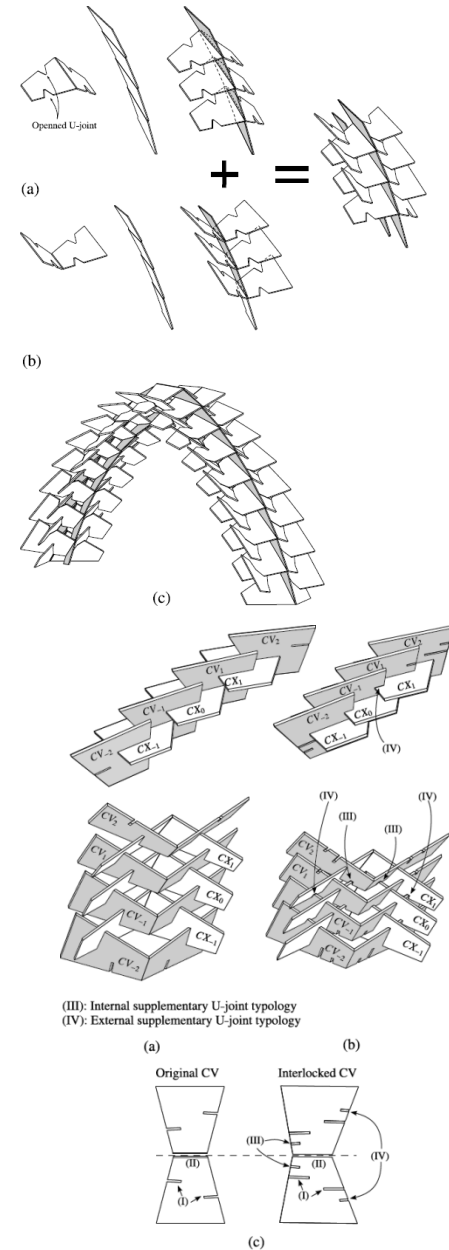


$|u|$ in mm

S, Mises in Pa



Structural improvement







ibois.epfl.ch

